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OCTOBER, 1971

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Gloucester Point, Virginia 23062

Dr. William J. Hargis, Jr.
Director

October, 1971

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INTRODUCTION

The demand for electric power in the United States is expected to double every 10 years. As hydroelectric power plant sites reach their full capacity, the demand for electricity will be met by the development of fossil fuel and nuclear power plants. The average thermal efficiency of nuclear power plants is presently about 32%. Therefore, a significant amount of heat is not utilized.

For large power plants, the once-through cooling method, in which water is withdrawn from an adjacent body of water and returned after being heated, is the most common one. However, the great amount of heat discharged into the water may result in changes in the physical and chemical properties as well as in the ecology due to the rise in temperature of the water.

The objectives of this study is to determine the region of the James River estuary which will be affected by the thermal discharges of the Surry nuclear power plant located at Hog Island and the temperature distribution within that region. The area under study is shown in figure 1. The cooling water is pumped in from the James River at the right side of Hog Island and returned at the left side.

The following is a progress report of the first year's work on this project.

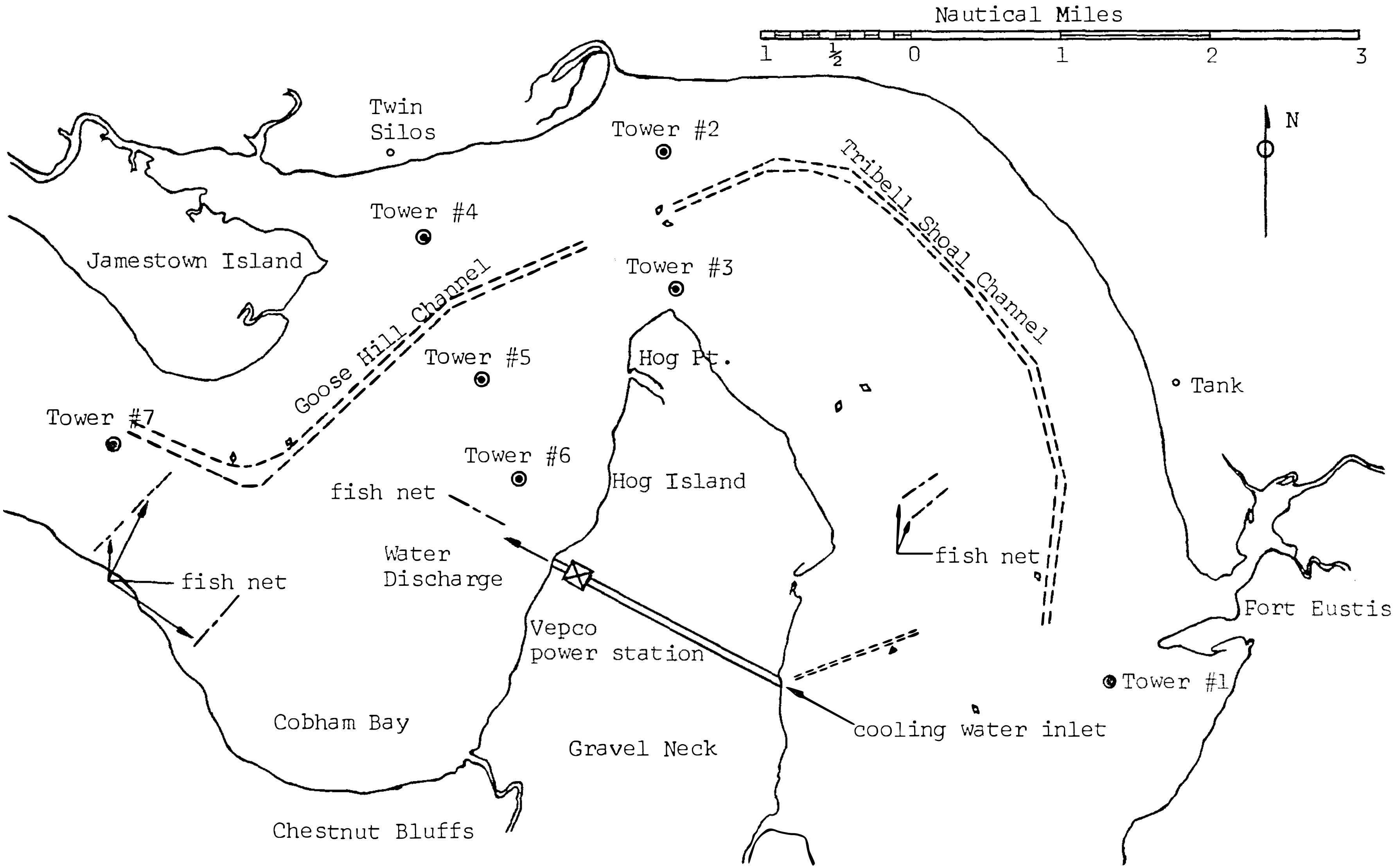


Figure 1. Hog Island at James River, Va.

MEASUREMENT SYSTEMS

Three environmental measurement systems will be used to take field data in this study. The first is a multi-sensor system located on a boat which serves as a mobile measurement platform. A 30-foot boat, the INVESTIGATOR, a Chesapeake deadrise with cabin and inboard engine, has been instrumented with nine temperature sensors, a dew point sensor, a salinometer, a fathometer, a current meter, a position marker, a heading sensor, and automatic data recording equipment. A block diagram of the instrumentation is shown in figure 2. The blocks numbered 1 through 8 represent instruments which measure parameters of the environment. A flow diagram shows the outputs of these instruments entering a digital data acquisition system and then a digital stepping magnetic tape recorder. Each sensor is sampled and digitized by the data acquisition system and then recorded on magnetic tape every 1.2 seconds. This gives 50 data points per minute, or 3,000 data points per sensor per hour which is the approximate time required to survey the discharge area. This data is recorded in IBM comptatible format and is interfaced directly with an IBM-360 computer. Table 1 shows each instrument, its sensors and what they measure.

The second system is a multi-sensor system located on towers in the James River near Hog Point which serve as fixed measurement platforms. Self recording tide gauges have been installed on two towers, #7, upstream, and #1 downstream from the Surry plant. Three anemometers, a wind vane, a net radiometer, five temperature sensors, two humidity sensors, a two-axis water current meter, a salinometer, a water pressure sensor, and automatic data recording equipment are installed on tower #6, the tower nearest to the discharge effluent. A block diagram for the instrumentation on tower #6 is shown in figure 3. The blocks numbered 1 through 8 are the measuring instruments. Their outputs are in turn sampled, digitized and recorded on 1/4 inch magnetic tape in a complementary binary coded decimal (BCD) format. The Braincon data system automatically turns on every twenty minutes and records each sensor eight times over a time period of about one minute before turning off again.[11] The Braincon tapes are converted by a tape coupler to 1/2 inch IBM compatible tapes when they are brought back from a field run of 10 days. These tapes are then interfaced directly with an IBM-360 computer. Table 2 shows the tower instruments, their sensors and what they measure.

The third is an infra-red sensor scanning system located in a plane. With the cooperation of NASA-Wallops, infra-red photographs will be taken from an airplane flying over the river. At the times of these flights, there will be instruments in the river which will measure the surface temperature of the water. These field measurements will then be used to help interpret the photographs.

Two monitoring courses are designed for the boat. One is the zigzag path shown in figure 4, designed for taking field data before the thermal plume is discharged. The other path, shown in figure 5, is designed for taking field data at the time the thermal plume is discharged.

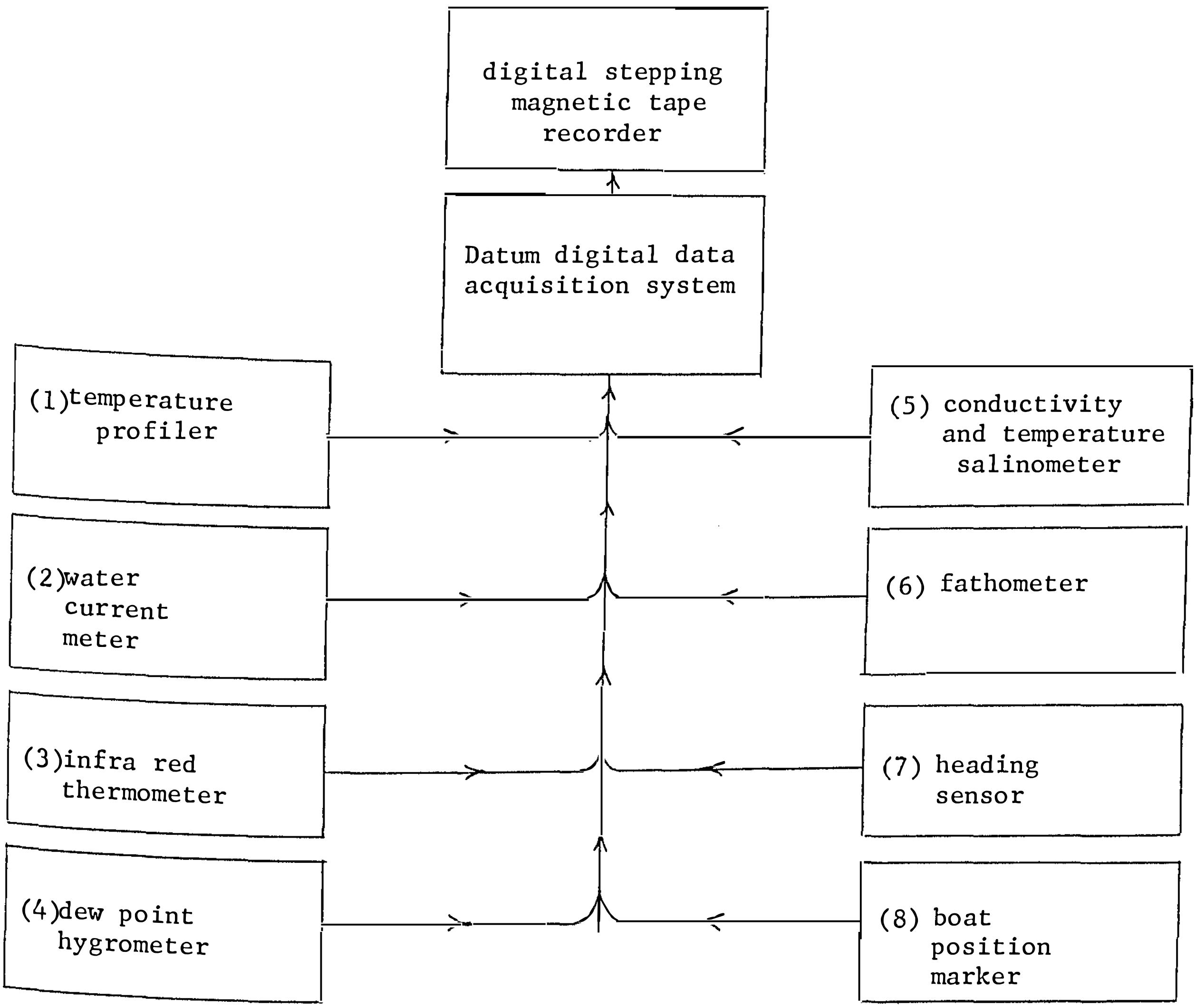


Figure 2. Instrumentation on board the Investigator

Instrument	Sensor	Measurement
infrared thermometer	thermistor bolometer	temperature at surface of water
temperature profiler	thermistor	temperature 1/2' below surface of water
	thermistor	" 3' " " " "
	thermistor	" 6' " " " "
	thermistor	" 9' " " " "
	thermistor	" 18' " " " "
	thermistor	" 24' " " " "
	thermistor	" 3' above " " "
	thermistor	" 6' " " " "
water current meter	strain gauge	velocity $\perp$ to keel in first 1/2' of water
	strain gauge	" // " " " " " " "
dew point hygrometer	controlled thermistor	dew point 6' above surface of water
fathometer	sound transducer	depth of water
boat marker	none	position mark recorded on magnetic tape
salinometer	conductivity cell	conductivity of water in first 1/2'
	thermistor	temperature " " " " "
digital compass	driven flux gate	boat heading

Boat instruments and measurements

Table 1

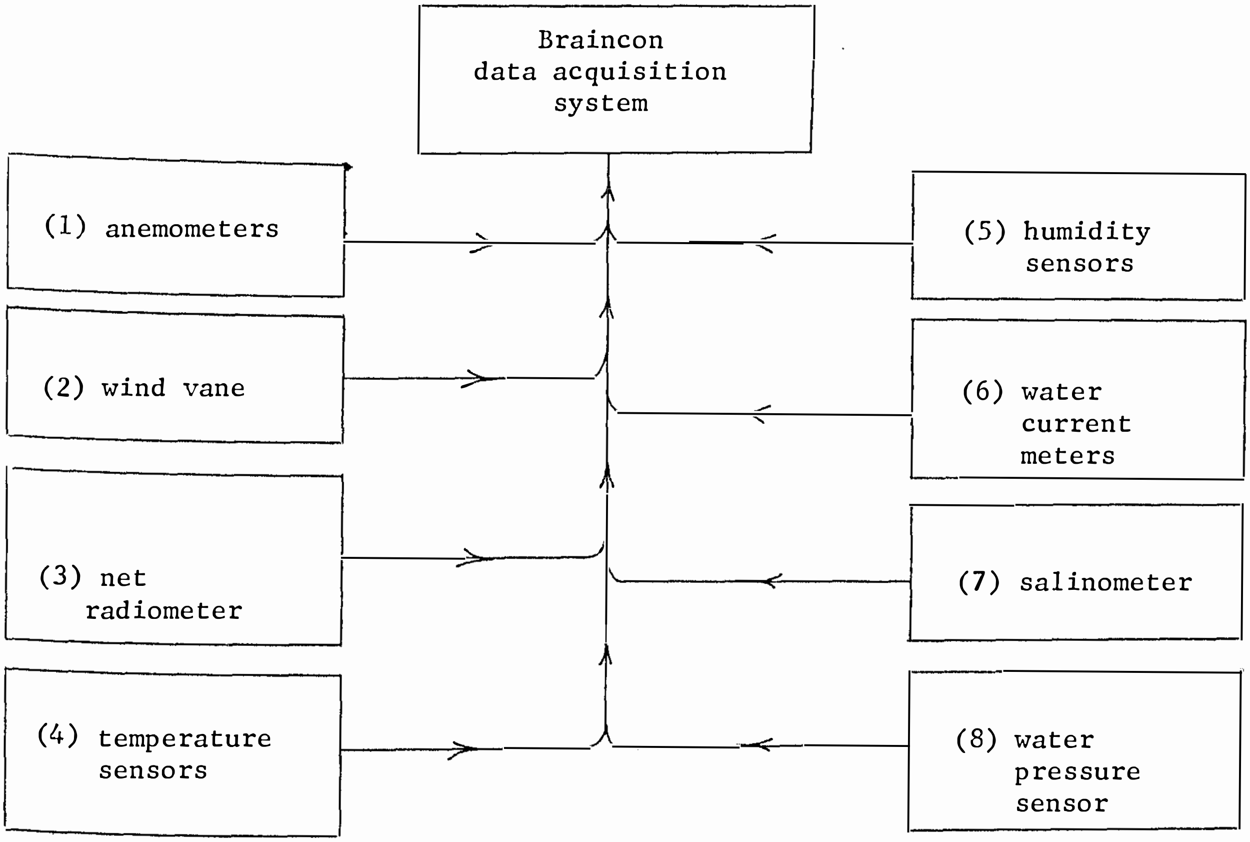
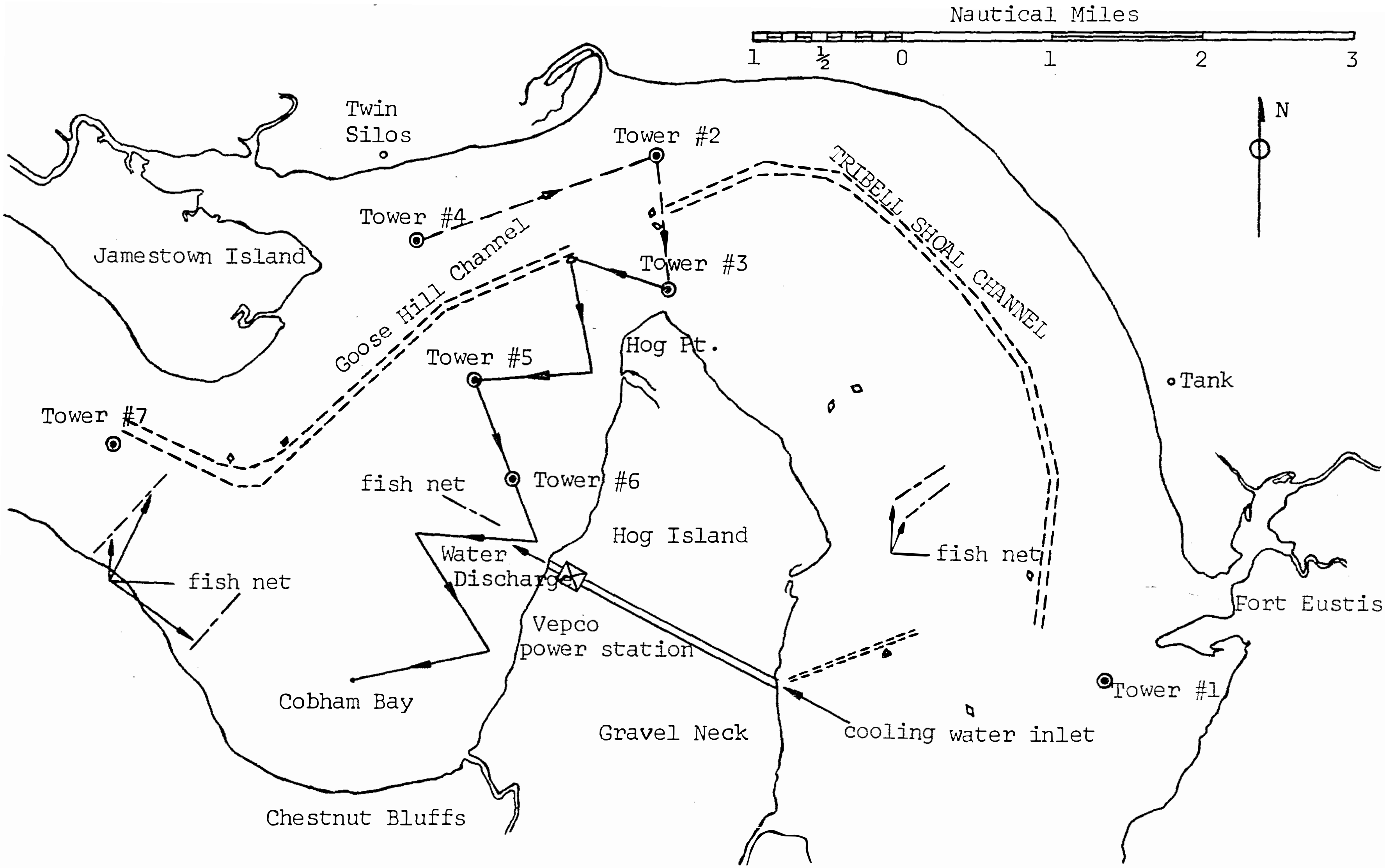


Figure 3. Instrumentation on Tower #6

Instrument	Sensor	Measurement
wind system	anemometer	wind speed 6' above surface
	anemometer	wind speed 12' above surface
	anemometer	wind speed 24' above surface
	wind vane	wind direction 28' above surface
net radiometer	thermopile	net radiation 8' above surface
temperature sensors	thermistor	temperature 6' above surface
	thermistor	temperature 28' above surface
	thermistor	temperature 1/2' below surface
	thermistor	temperature 3' below surface
	thermistor	temperature 6' below surface
humidity sensors	crystal	relative humidity 6' above surface
	crystal	relative humidity 28' above surface
water current meter	strain gauge	velocity $\perp$ to shore, at a 7' depth
	strain gauge	velocity // to shore, at a 7' depth
salinometer	temperature compensated conductivity cell	salinity at same depth
water pressure	diaphram	depth of sensor from surface

Table 2

Tower instruments and measurements


Nautical Miles
1
½
0
1
2
3
N
Twin Silos
Tower #2
TRIBELL SHOAL CHANNEL
Tower #4
Jamestown Island
Goose Hill Channel
Tower #3
Hog Pt.
Tower #5
Tank
Tower #7
fish net
Tower #6
Hog Island
fish net
fish net
Water Discharge
Vepco power station
Fort Eustis
Cobham Bay
Tower #1
Gravel Neck
cooling water inlet
Chestnut Bluffs

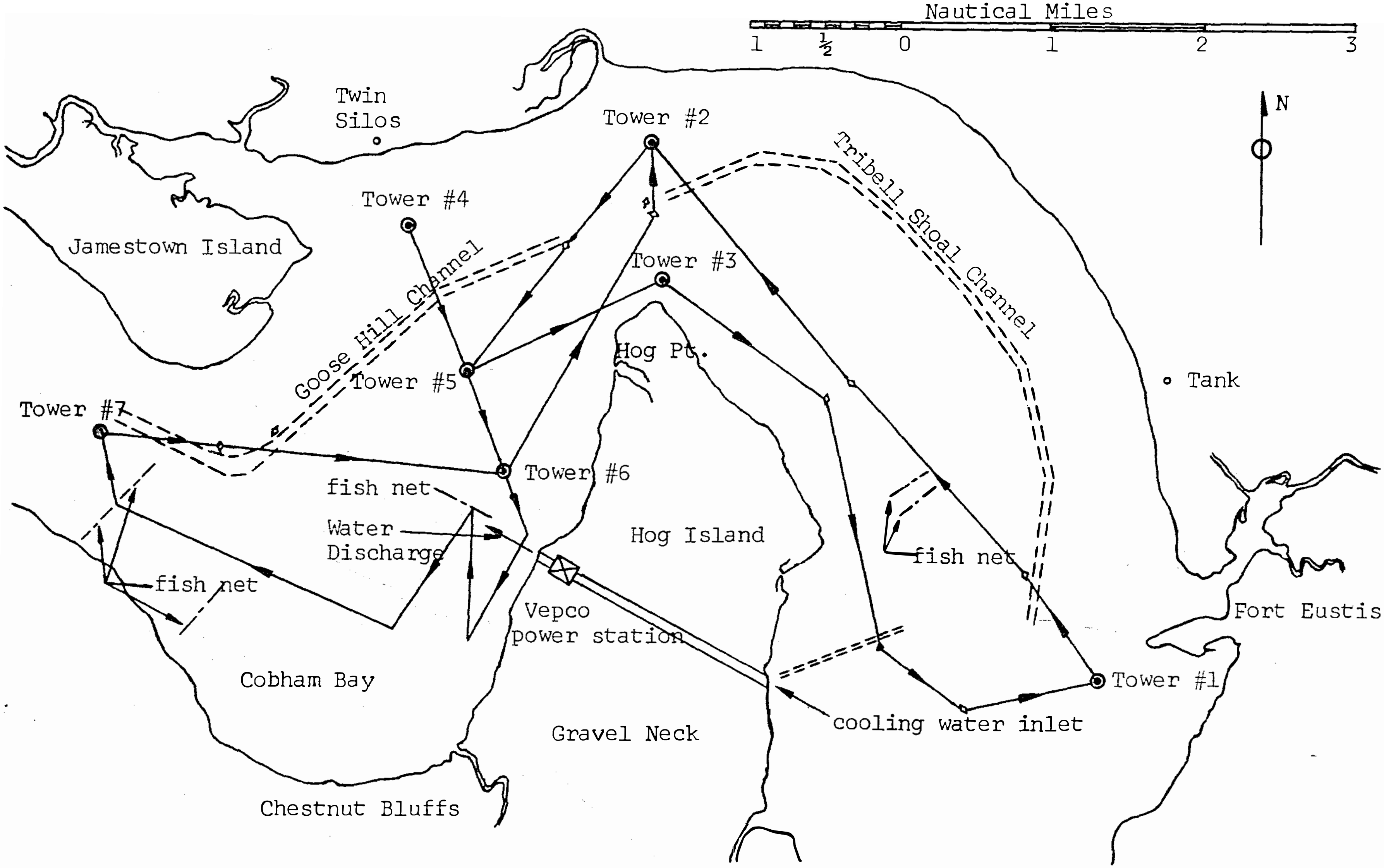


Figure 5. Path II of INVESTIGATOR

MOVING BOAT INSTRUMENTS

The boat instrumentation was acquired by making use of available equipment, surveying the market for new equipment and building equipment of our own design.

It was discovered that the pre-amplifier on the available infra-red thermometer was unusually heat sensitive when enclosed in the electronics housing. The malfunction was corrected when a faulty electrolytic capacitor was discovered and replaced.

The water current meter is a two axis strain gauge type[3] A well regulated D.C. power supply had to be designed and built for its electrical exitation.

The salinometer is a complete instrument in itself. It only needed a 500 resistor across its temperature output for proper interfacing with the tape recording system.

The fathometer is a chart recording instrument. A stylus is electrically energized to put a mark on the chart paper when the sound transducer is energized for transmission, and again when it picks up the returning echo. A motor drives the stylus across the chart paper at an appropriate speed so that the depth is scaled to read in feet on the chart. This kind of output was not compatible with the tape recording system. The tape recording system can accept two types of inputs, analog inputs and binary coded inputs. An electronic counter was the obvious answer to this interfacing problem, and one was obtained from an outside manufacturer. It counts at a fixed rate between the energize and echo signals, displays the depth in feet, and transmits the depth in BCD to the data system

The dew point hygrometer is a thermo-electric type. By means of a light source and photocell the hygrometer senses when dew has formed on a cooling mirror surface and stops cooling the surface. A thermistor embedded in the surface senses the temperature and the corresponding voltage output from a bridge circuit is recorded.

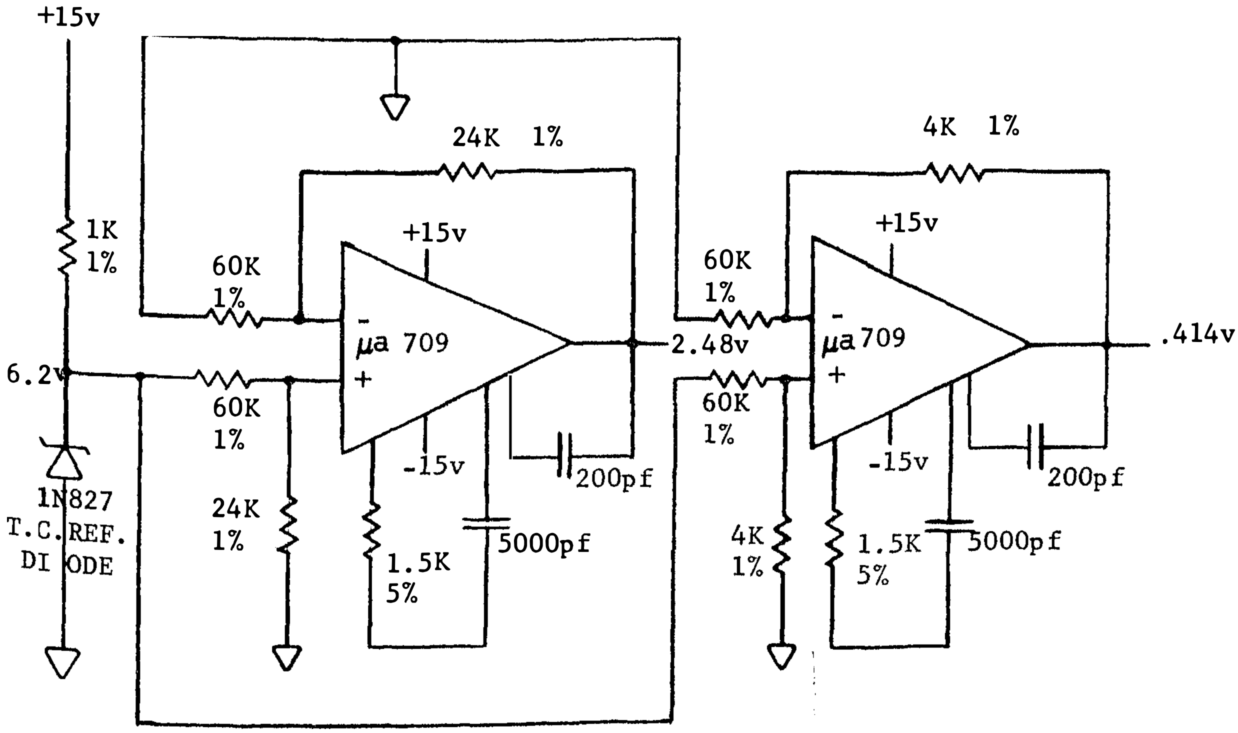
The heading sensor is a motor driven, magnetic flux gate. The sensor is suspended from gimbals, is pendulous, and is damped. This is done in an attempt to keep the sensor rotating in the local horizontal plane regardless of any motion the mount may experience. There are two ruled disks which rotate with the sensor. One is a reference direction disk which puts out an electronic pulse when the sensor is at a fixed reference angle to the case, while the other puts out a pulse every degree of arc. The sensor itself puts out a pulse when it passes through the earth's horizontal magnetic null. Thus the number of 1^{o} pulses between the reference pulse and the sensor's pulse is the heading information. An electronic counter to display the heading and provide a BCD output for interfacing to the Datum system has been purchased.

A two cylinder gasoline engine driving an electric generator capable of 4kw is used to power the boat system. The two cylinder engine was used in preference to a one cylinder type for smoother running conditions and a more stable 60 cycle output.

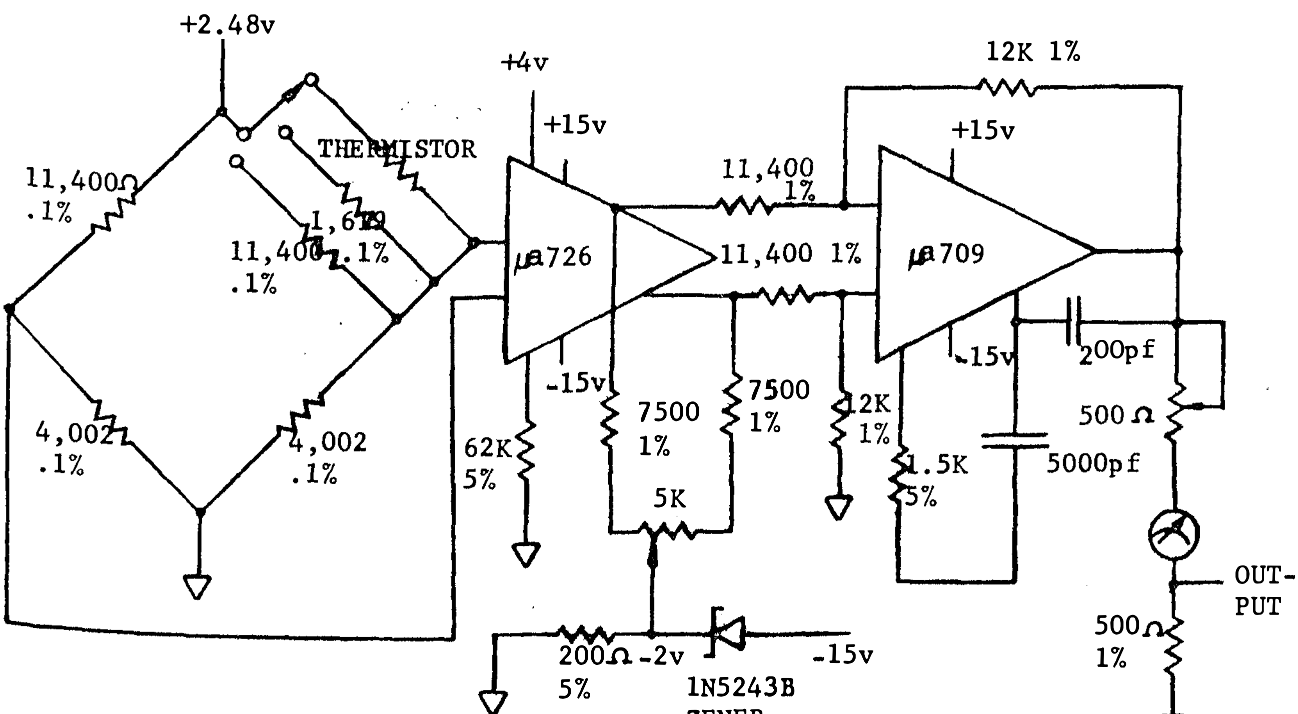
The temperature profiler is one of the instruments which was designed and built here. Thermistors mounted in glass probes are used as water sensors. They are waterproof, have a fast time constant, and are interchangeable without calibration. The stainless steel thermistor housing is configured to mate with a standard under-water connector. The thermistor probe is potted into the end with silicon rubber molded under pressure for a leakproof seal. Thermistors mounted in small glass beads are used as air temperature sensors. Electronic components include a bridge circuit, a power supply, a buffer amplifier and a preamplifier. These were designed and built here. Circuitry diagrams appear in figure 6.

The bridge circuit is a basic resistance type with the thermistor or one of two calibration resistors making up the fourth leg. One calibration resistor is equivalent to the thermistor at $0^{o}C$ and zeros the output of the bridge. The output meter is then zeroed by means of the 5k adjustable resistor which is part of the "Fairchild" μa 726 amplifier circuit. The other resistor is equivalent to the thermistor at $50^{o}C$. The output meter is set to 1 volt when this full scale resistor is switched in, by means of the 500 adjustable resistor which is part of the "Fairchild" μa 709 amplifier circuit. The "Fairchild" μa 726 is a temperature controlled differential transistor pair. It is used in a differential emitter follower configuration. In this configuration it has a high input impedance, > 1M , and a low output impedance. The "Fairchild" μa 709 is an integrated circuit pre-amplifier. It is used to set the gain of the circuit.

THERMISTOR POWER SUPPLY



THERMISTOR BRIDGE & READOUT



NOTE: all .1 & 1% Rs, ± 25 ppm/°C

Figure 6. Thermistor circuitry

The power supply for the bridge circuits consists of a temperature compensated zener diode as a reference and two "Fairchild" μa 709 amplifiers which set the gain and power the bridges.

The circuits were built on plug-in type Vector circuit boards. An aluminum enclosure called a Vari-pak and plug connectors were bought from the Elco Company. The electronic components were chosen so that a 50^{o}C change in temperature allows only a 0.1^{o}C false indication due to their temperature coefficients. The thermistors selected to sense temperature have the same accuracy, 0.1^{o}C.

The boat position marker has two decade thumbwheel switches which are used by the experimenter to mark boat position. The numbers dialed in are entered on the magnetic tape at the command of the experimenter. The marker is used as the boat passes buoys, towers, or other coordinates selected as position references for an experiment. Circuitry for the boat position marker appears in figure 7. The thumbwheel switches put out complementary BCD signals. The signals are inverted by integrated circuit "nand" gates and then drive a D/A converter. The analog voltage output is scaled by the "Fairchild" μa 709 amplifier and proceeds into the tape recording system.

The Datum data acquisition system was modified to allow full BCD information to be recorded on tape in each of the previous single bit positions.[8] A circuit board added to the Datum system, shown in figure 8, brings in the 2's, 4's, and 8's bit along with the existing 1's bit. At the appropriate time the BCD representation is "ored" onto the 1, 2, 4, & 8 bus

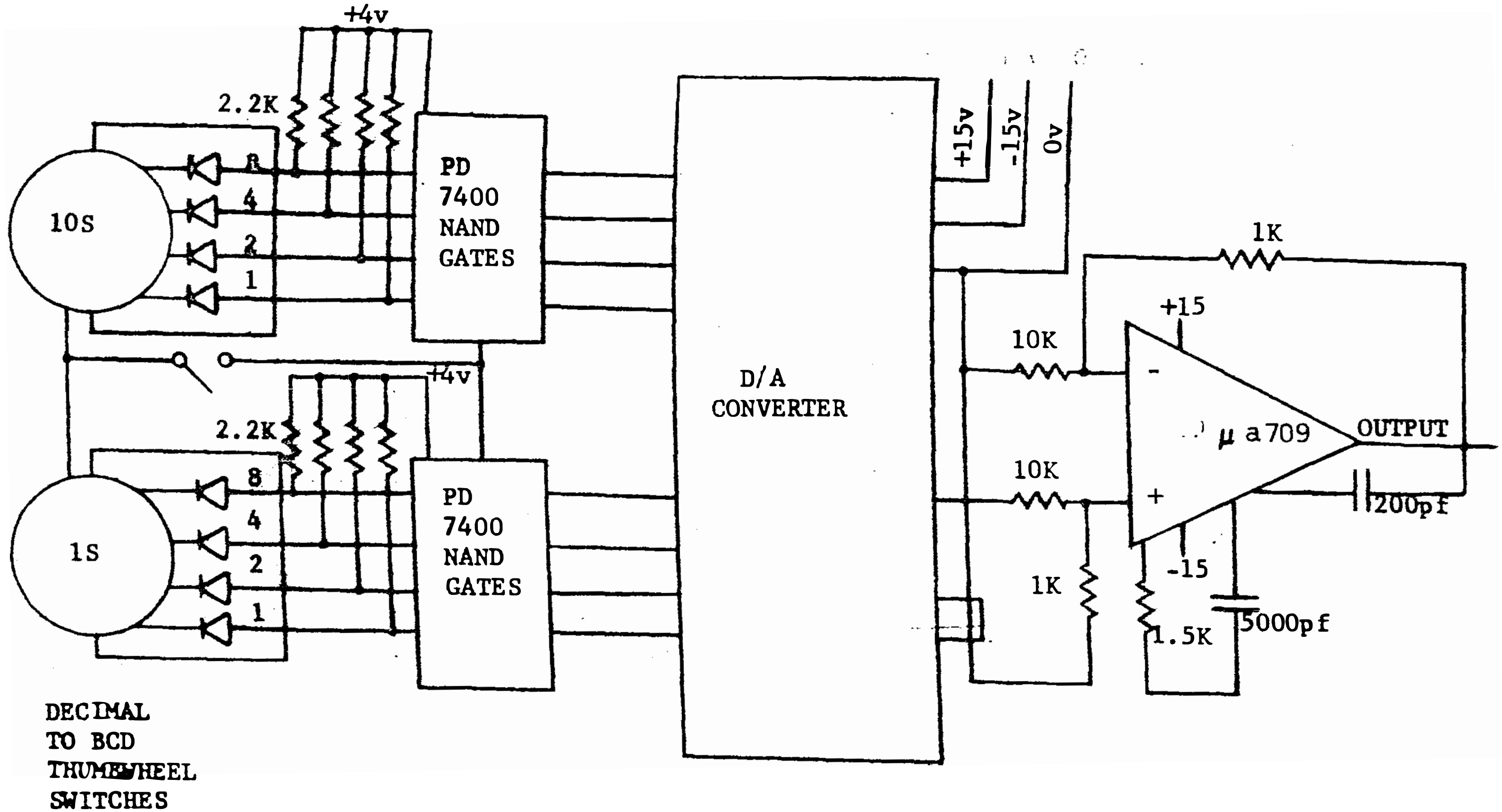
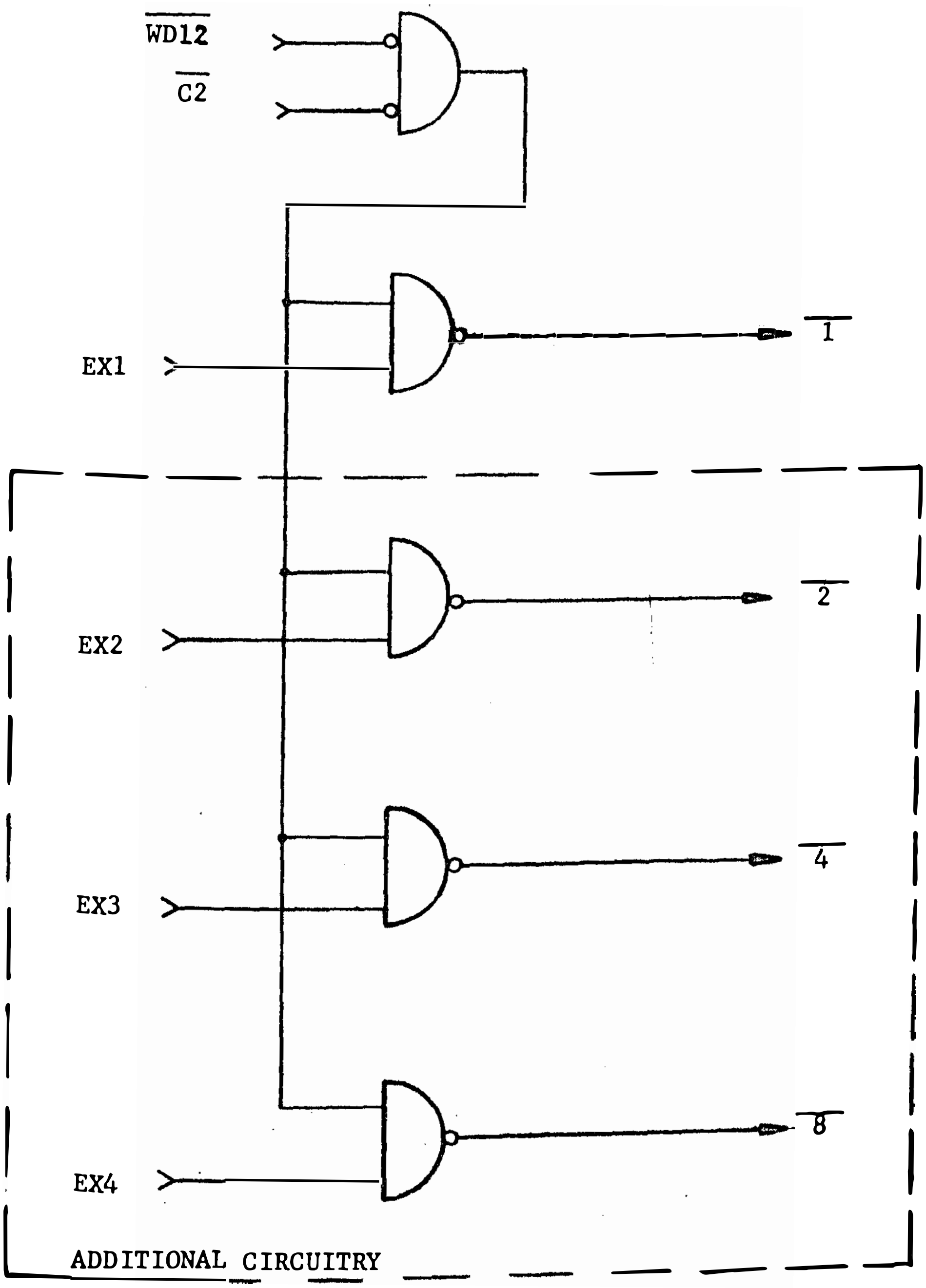


Figure 7. Boat position marker



CHARACTERISTIC EXPANSION OF DATUM SYSTEM

Figure 8. Datum System modification

of the recorder and recorded on tape. The circuits used are all integrated "nand" and "nor" gates.[6]

D.C. power supplies were built to power the electronics for the temperature profiler, the buoy marker, and the drag sphere current meter. These are regulated supplies. Circuit diagrams for them appear in figure 9.

A board of amplifiers was constructed to raise the output level of some of the instruments. This increases the resolution of the instruments and normalizes them to 1v full scale, going into the Datum data recording system. "Fairchild" μa 709 integrated circuit amplifiers were used to do this. A circuit diagram appears in figure 10.

Instrument mounts were designed and fabricated here. Three metal mounts were made for some instruments on the boat. Two are shown in figure 11. The top one is for the infrared thermometer and the drag sphere current meter. Its basic configuration is that of a triangular pyramid, which has been modified to fit on the bow. The infrared thermometer looks straight down at the unperturbed water surface. The current meter is attached to the end of a movable pipe so that some vertical and rotational adjustment in the horizontal plane is possible. The other mount is for the top three water thermistors. They are mounted inside small metal cylinders which are welded to a steel rod. The rod is braced fore and aft by a steel cable which is tied forward with a breakable test line. If an object is hit in the water, the test line will break, and the thermistor mount will swing back and up.

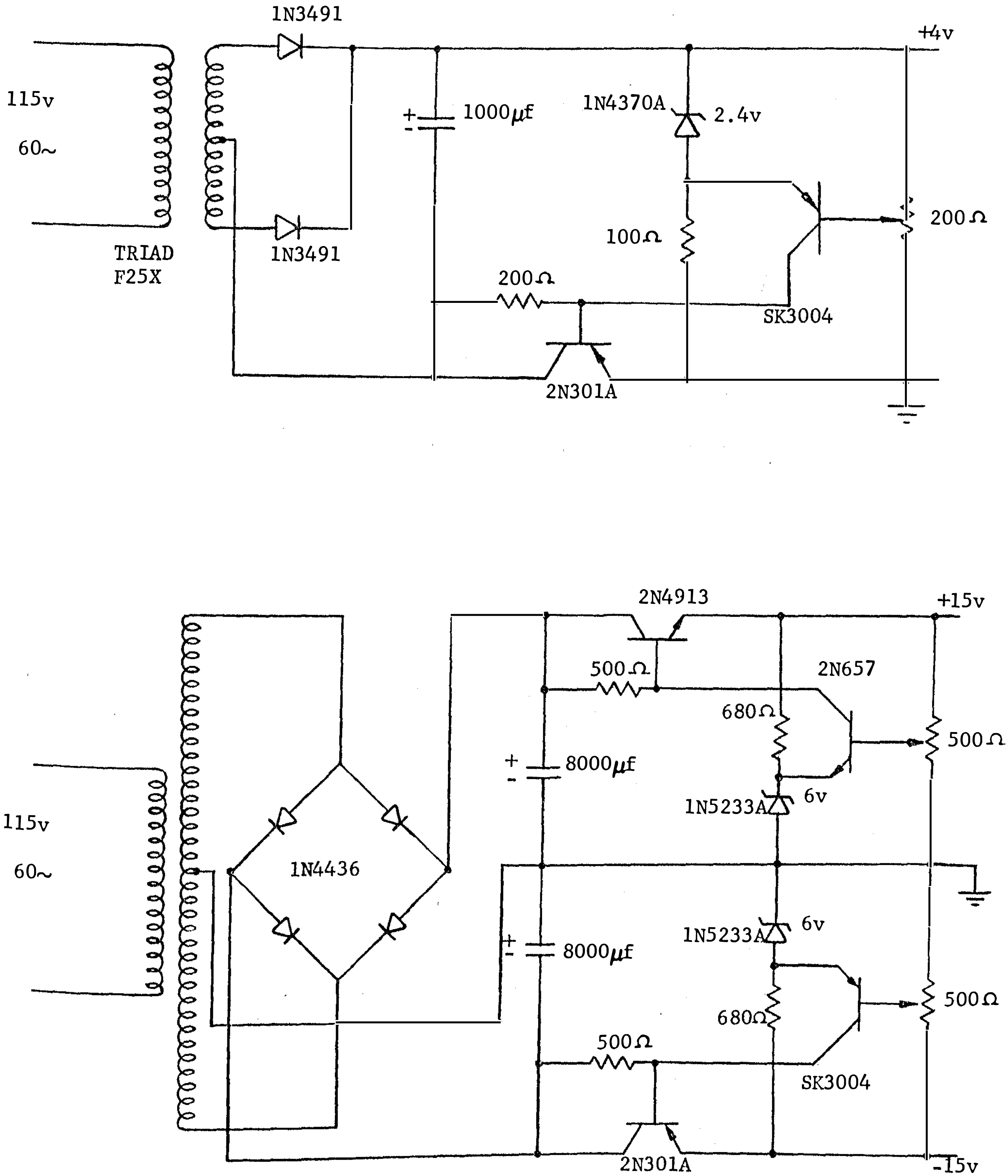
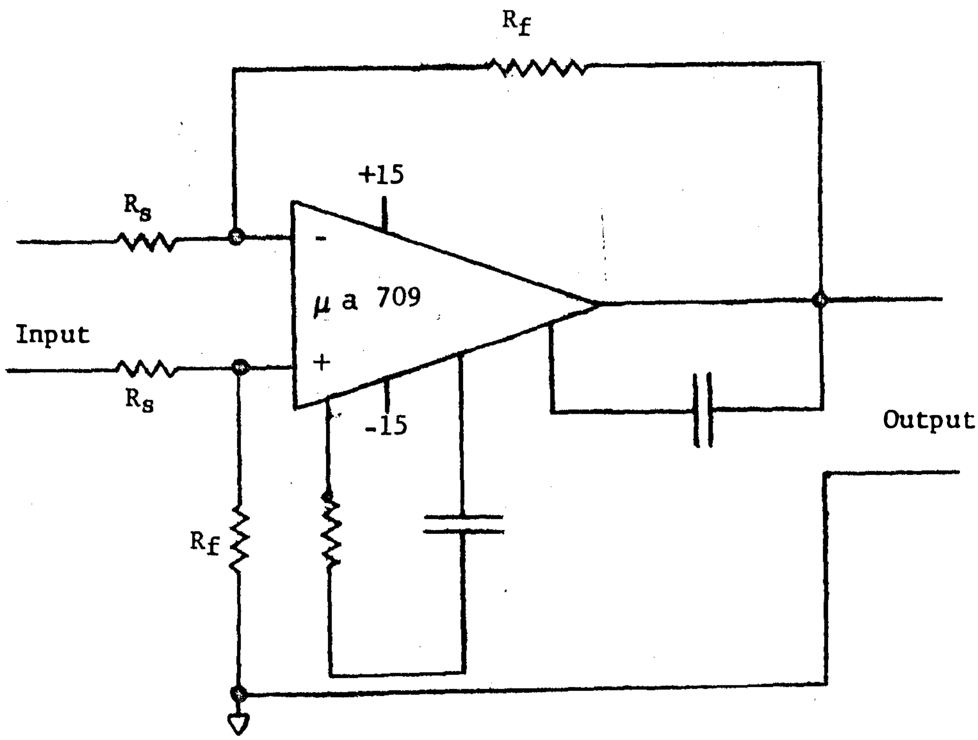


Figure 9. D.C. power supplies



Gain = $\frac{R_f}{R_s}$

Figure 10. Typical amplifier

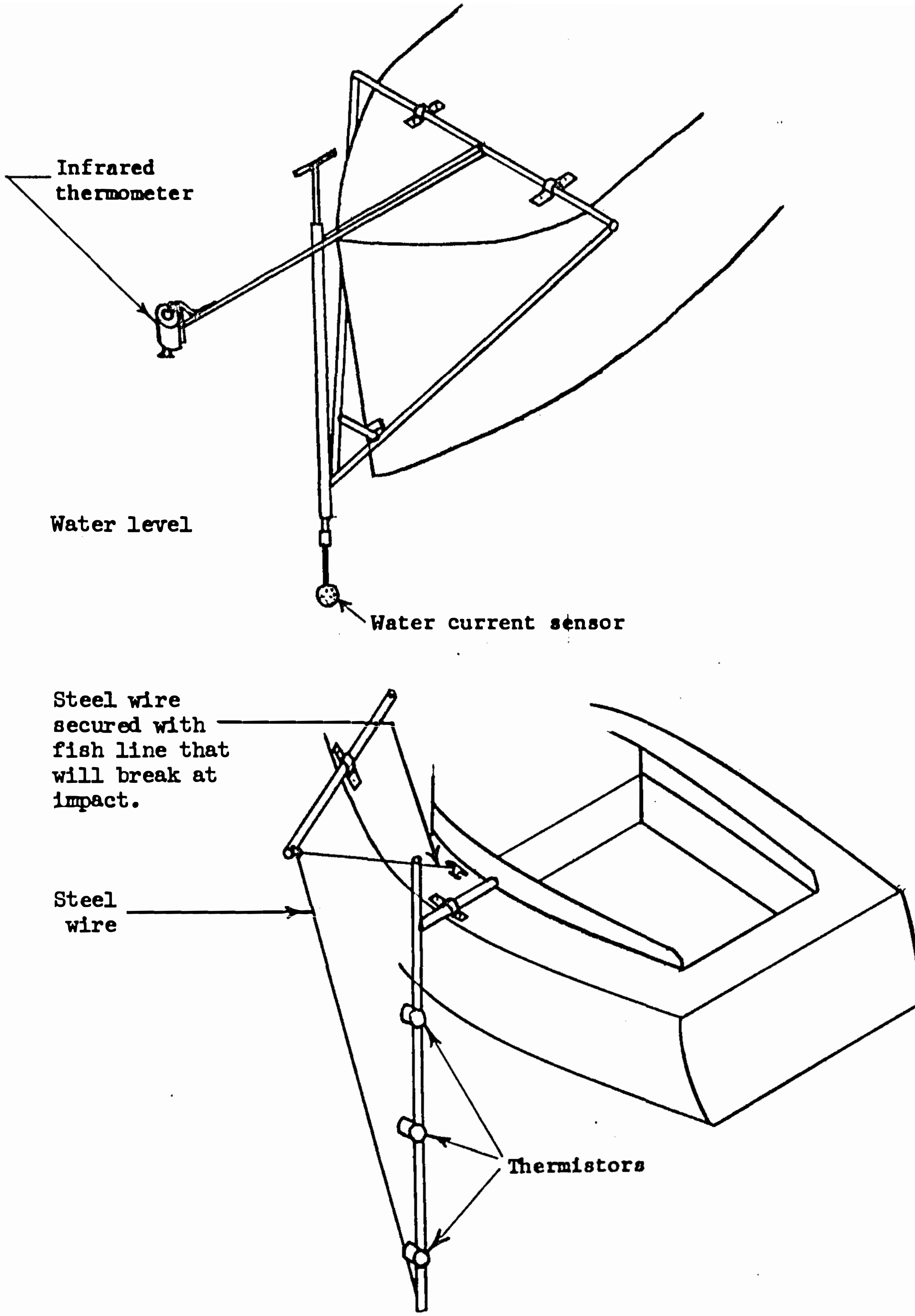


Figure 11. Boat instrument mounts

The third mount, which is not shown, goes over the other side of the boat from the thermistors. It holds the fathometer transducer and an underwater pump. The pump supplies water to a basket in which the salinometer is mounted. The weight of the water in the basket helps to hold this mount down on the side of the boat.

Wooden cabinets for the electronics were placed forward in the cabin of the boat. They were shock mounted with foam rubber and strapped down with pieces of rubber inner tubing.

TOWER INSTRUMENTS

The CM^2 salinometer is a complete salinity indicating instrument. That is, the conductivity and temperature of the sample are measured and mixed electronically in such a way that salinity is the output from the instrument. It is directly compatible with the Braincon data recording system.

A drag sphere current meter is used to measure river currents. It is directly compatible with the Braincon data system.

The wind system sensors consists of three low friction anemometers, and a no-gap weather vane for wind direction. The no-gap provision of the weather vane allows a continuous electrical output from the vane through a mechanical angle of 0^{o} to 540^{o}. A two channel strip chart recorder makes continuous recordings of the wind direction and one speed. Two electronic translators were built to convert the frequency outputs of the other two anemometers to D.C. voltage for recording purposes. All of these wind sensors are now ready to be interfaced directly with the Braincon magnetic tape data recording system.

The net radiometer was made by Thornthwaite Associates. The sensor is a thermopile. The junctions are divided evenly on both sides of the sensor which is a flat disk, about the size of a half dollar. It is oriented so that the flat is perpendicular to the local vertical. It will measure the radiation coming from the sky minus the radiation from the water's surface. A continuous record of the net radiation at tower #6 in the James River is obtained by recording the amplified signal on a Rustrak strip chart recorder. The Braincon system will record a sampled and digitized record of the net radiation.

Thunder Scientific relative humidity and air temperature sensors and electronics were used. The air temperature sensor is a thermistor. The humidity sensor is a semi-conductor crystal which admits and discharges moisture to and from its crystal lattice. This results in a change in impedance which is translated into a DC voltage which is recorded by the Braincon system. Electronics convert the thermistor resistance to a DC voltage which is recorded directly.

The pressure sensor is a diaphram type. It is placed underwater and vented by a hose to the atmosphere. The diaphram moves due to a force applied by water pressure on one side pushing against atmospheric pressure on the other until the diaphram itself equalizes the pressure difference. A variable resistor excited with DC voltage and attached to the diaphram puts out a voltage signal proportional to the motion which is proportional to the depth.

Three Yellow Springs thermistors indicate water temperature. They time share one bridge circuit inside the Braincon system. Both the inputs and the outputs of the bridge are switched to record each thermistor's temperature.

Two Fischer and Porter tide gauges, used on towers #1 and #7, are complete self-contained measuring and recording units. Their outputs are recorded in binary format on punched paper tape.

The construction and installation of instrument mounts on tower #6 in the James River requires additional work. A drawing of this tower and its instruments is shown in figure 12. Two 10' sections of T.V. tower are used for the wind system. The platform on the VEPCO (Virginia Electric and Power Company) river tower is a 5 foot equilateral triangle. An eight foot steel pipe is extended from one corner out over the water to guy the wind tower and to support the net radiometer. The net radiometer sensor is mounted on the outer end. The wind tower is guyed to two corners of the triangle and to the end of the steel pipe and down to one of the river tower's cross braces as shown in figure 12.

The Braincon data system will be moored underneath the center of the river tower. The main mooring cable will be rigged to always stay in place, but the capsule may be raised and lowered for servicing. The three water thermistors will be mounted on a floating, damped cylinder, in order to keep them at a constant depth regardless of tide and river level. This cylindrical float will be constrained to move up and down on another mooring cable. The current meter, salinometer, and pressure sensor will be bracketed directly to the legs of the tower. Final positions of the instruments will be such that a correlation can be made between them and the moving boat instruments each time the boat passes the tower.

Float type tide gauges are used on the other two VEPCO towers, #1 and #7. T.V. tower sections hold a large diameter fiberglass pipe which encloses the float. These sections mate

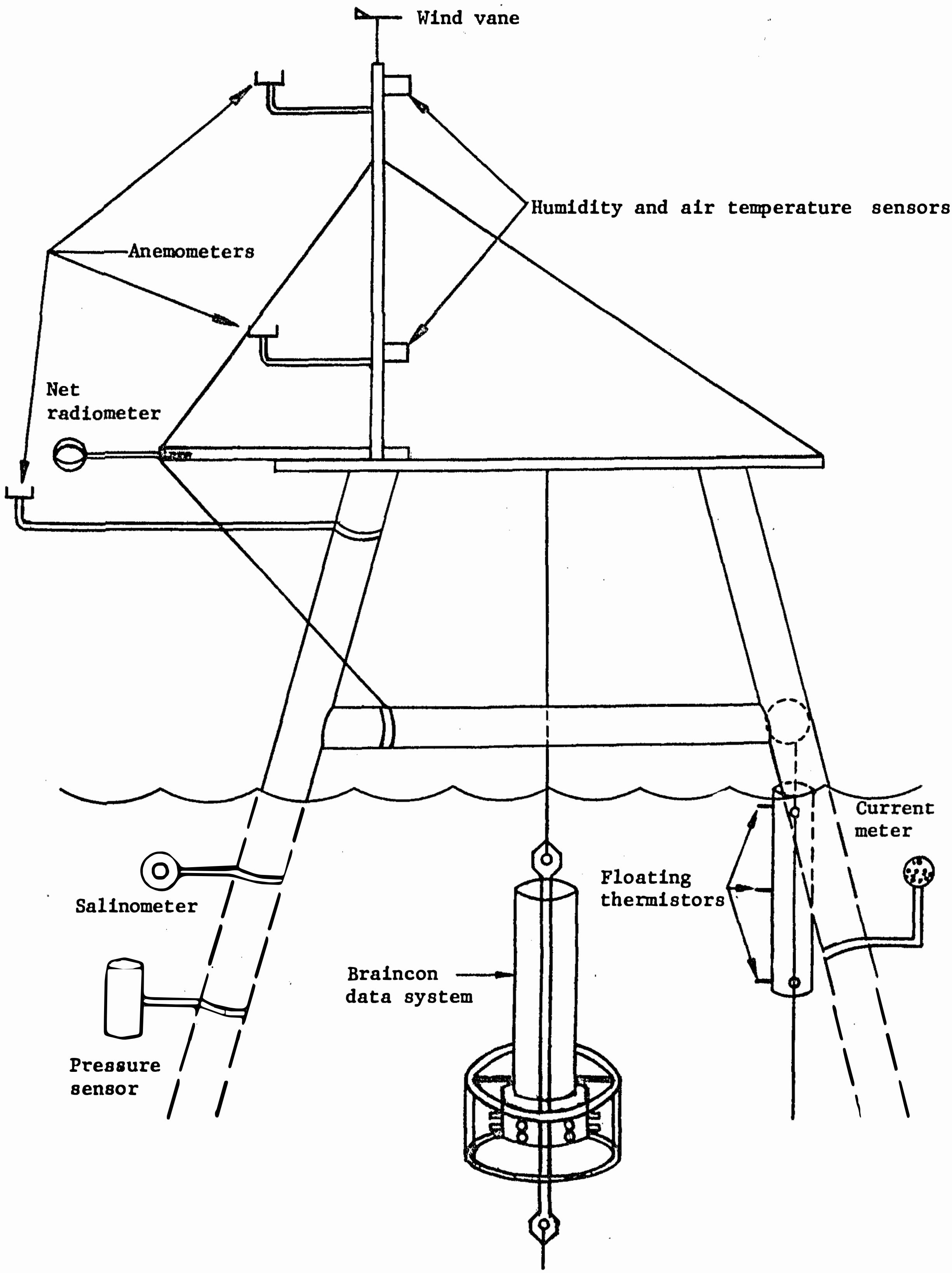


Figure 12. Tower #6 mounts

with the tide gauge which is placed on one side of VEPCO's triangular platform and extend into the water far below the lowest expected tide level. The end of the fiberglass pipe, in the water, is cone shaped with a small hole at the apex which admits water to the float inside. In this way wind and waves are effectively damped out of the tide gauge readings.

INSTRUMENTATION ERROR ANALYSIS

This is an analysis of the errors which are present in the measurements made by the boat system. The measurements can be thought of as signals which flow from the physical medium, into the sensors, through the instruments and into the computer. At various points in this flow, there are summing junctions where errors add to the signals.

The first point of analysis is the output of an instrument. Information on instrument measurement error is found in instrument catalogs and specification sheets. An instrument measurement error table for those instruments of the boat system is shown in Table 3. This table is abridged from Table 9.

Table 3

Instrument Measurement Error

Instrument	Accuracy	Range
Temperature profiler		
Water thermistor	± 0.2°F	23 to 95°F
Air thermistor	± 0.2°F	14 to 104°F
EG&G dew point hygrometer	± 1.0°F	-40 to 122°F
Barnes infrared thermometer	± 0.75°F	20 to 100°F
Martek salinometer		
Thermistor	± 0.6°F	28 to 86°F
	± 0.2°F	28 to 50°F
	± 0.2°F	46 to 68°F
	± 0.2°F	64 to 86°F
Conductivity cell	± 0.1 mmho/cm	0 to 65
	± 0.1 mmho/cm	0 to 10
Raytheon fathometer	± 1.0 inch	0 to 205 feet
Lundy heading indicator	1°	0 to 360°

The next point of analysis is the output of the multiplexor and digitizer. The Datum digital data acquisition system records data through twenty separate channels, one channel for each instrument. Therefore the measurement error of each instrument passes separately through the data acquisition system. It appears at the output multiplied by the gain and gain error of the Datum System. The bias error of the Datum System and errors due to sampling add to it here. The gain and bias errors are measured and will be removed later in the computer at the time of data processing. The errors due to sampling are discussed in detail in the next few paragraphs.

The choice of an appropriate sampling interval is important in taking field data digitally. The primary consideration is the fidelity of the reconstructed symbol. High fidelity is achieved by using a bandwidth which is large enough such that after signal reconstruction, there is only a minimal loss of the original signal. The moving boat system measures natural signals in both time and space. The thermal gradients for instance were assumed to have time constants on the order of minutes and space constants on the order of feet. To reconstruct these signals and still be able to do a several mile survey within one hour, meant that the fastest sampling speed of the Datum System[8] had to be used and the cruise speed had to be chosen to give a space constant of a few feet. The actual numbers picked were a sampling interval of 1.2 seconds, a cruise speed of 5 knots, and a space constant of 10 feet.

Another important consideration is that of matching instrument time constants to the sampling interval. Doing this prevents the data from being aliased.[4]

Aliasing (figure 13) results from high-frequency events which add variance to the record. Figure 13 illustrates how the variance from this type of event is folded into the record and reappears at a lower frequency.

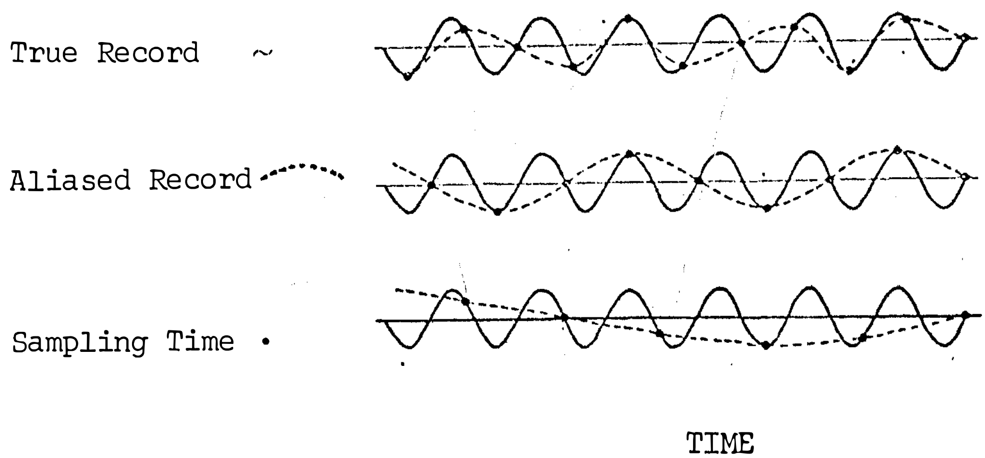


Figure 13. Effects of observing periodic events at sampling intervals more than one-half the period.

Examination of figure 13 shows that a sampling interval larger than one-half of the period of any cyclic event will result in aliasing. Where the sampling interval equals one-half of the period, the event will never be seen. Only when the sampling interval is less than one-half of the period can the event be measured.

A table containing the "time constant" of every instrument of the boat system is shown below:

Table 4

Instrument Time Constant

Instrument	Time Constant
Water Current Meter	
Temperature Profiler	
Water Thermistor	0.4 sec
Air Thermistor	1.0 sec
EG&G Dew Point hygrometer	1.0 sec
Barnes Infrared Thermometer	0.5 sec
Martek Salinometer	
Thermistor	1.0 sec
Conductivity Cell	
Raytheon Fathometer	0.1 sec
Lundy Heading Indicator	0.5 sec

From the table, the best sampling interval would be .1 sec. However, the fastest interval available by the Datum System was 1.2 sec. This means that some of the measurements will be aliased. Hopefully there will not be much signal energy in it. The only real way to verify this and to get a quantitative feel for the alias error would be by a pre-survey with a high speed sampling instrument.

The last point of analysis of the instrumentation errors is in the computer. The measurement signal enters as a digital number with the dimension of volts and is converted in software into a digital number with the dimensions of the physical parameter which was measured. During this process of converting raw data, data conversion errors occur. They are caused by non-linearities in the curves which relate the voltage to the physical parameter measured. A detailed discussion of the moving boat data conversion is given below.

Temperature Profiler Data Conversion:

The temperature profiler data can be converted from voltage to temperature (^{o}C or ^{o}F) directly from Table 8. However, in order to save time, the following two equations which relate the temperature, voltage, and resistance can be used. Equation (5-1) is obtained from thermistor circuitry (see fig. 6). Equation (5-2) is obtained from "Fenwal Electronics Thermistor Manual Bulletin No. EMC-5".[2]

$$R = -R_2 + 1/\left[(2EA/C \cdot R_2 \cdot EI) + 1/(R_1 + R_2)\right] \quad (5\text{-}1)$$

Where
R = Thermistor resistance
R_1 = 11,400 ohms
R_2 = 4,002 ohms
EI = Input voltage, 0.5 v.
EA = Output voltage
C = 8.8469

$$\frac{R(T)}{R(T_o)} = e^{\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)} \quad (5\text{-}2)$$

Where
$R(T)$ = Resistance at absolute temperature T
$R(T_o)$ = Resistance at absolute temperature T_o
e = 2.718
β = Constant which depend on the material used to make the thermistor.

Based on table 8, β values are determined from equation (5-2) for three temperature ranges. Equations (5-1) and (5-2) are then combined, eliminating R(T). The resulting conversion equation is of the form T = f(EA). It is used in the voltage to parameter computer program. Its accuracy is computed by taking values of EA from table 8, substituting them into the conversion equation and comparing T with the values of temperature in table 8. The β values, the accuracy of the conversion equation and the temperature ranges are tabulated below.

β - value	Accuracy	Ranges
3391	$\pm$ 0.1°F	32 to 68°F (0 to 20°C)
3410	$\pm$ 0.1°F	68 to 86°F (20 to 30°C)
3427.5	+ 0.15°F	86 to 104°F (30 to 40°C)

Dew Point Hygrometer Data Conversion:

Dew point hygrometer data can be converted by using figure 14.[9] In order to save time, a fourth order equation obtained from regression analysis is used which fits the curve shown in Figure 14. The equation is:

$$T \simeq -\ 40.75411 + 5.956E - 0.20427E^2 + 0.0046148E^3 - 0.000032405E^4 \qquad (5\text{-}3)$$

Where T = Temperature, °F

E = Output voltage, mv

The regression curve corresponding to equation (5-3) is shown in Figure 15. The accuracy and temperature range for this equation are tabulated below.

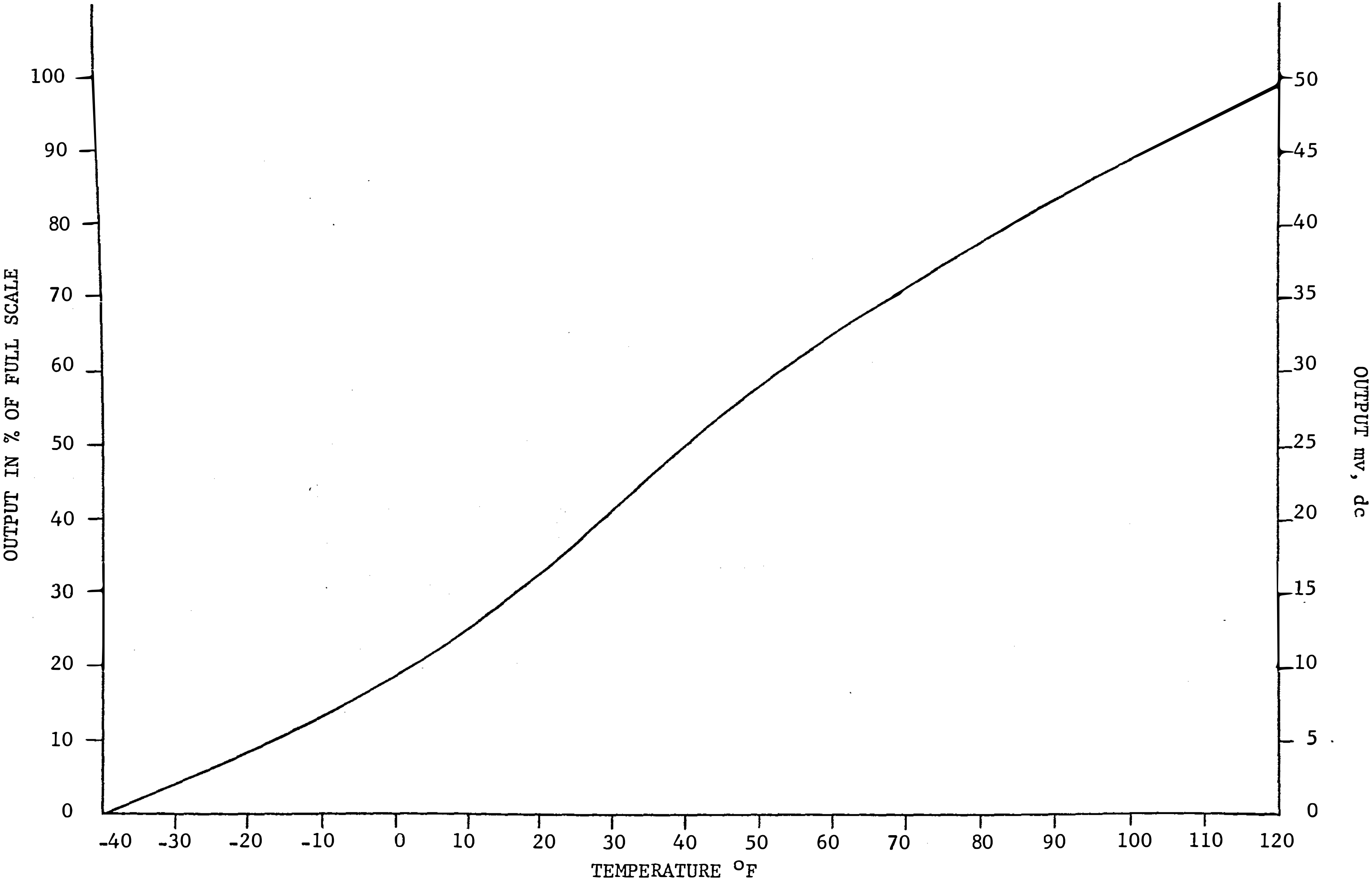


Figure 14. Temperature vs Percentage Output for Dew Point Detector

Accuracy	Range
+ 0.3°F	- 40 to 122°F

Salinometer Data Conversion:

(a) Temperature Sensor:

Table 5 gives the relationship between temperature values and thermistor resistance of the temperature sensor.[10] Before using this table, an equation must be found to relate the output voltage of the temperature sensor to the resistance of the thermistor. The equation can be obtained through the temperature sensor circuit, Figure 16. Referring to Figure 16, the following equation is obtained:

$$V_o = \left(\frac{3000}{3000 + R_t} - \frac{3000}{3000 + R_b}\right) \cdot V_i \cdot K \quad (5\text{-}4)$$

Where K = Gain

R_b = Bridge resistance

R_t = Thermistor resistance

V_o = Output voltage

V_i = Input voltage, 1.5v

In equation (5-4) the unknowns K and R_b, can be found by the following method.

At the time of calibration, the output voltages corresponding to 8°C and 18°C were obtained. From table 5, R_t values corresponding to 8°C and 18°C are obtained. After substituting the values of V_o and R_t into equation (5-4), two simultaneous equations containing K and R_b result, which can be solved for these unknowns.

Table 5

THERMISTOR VALUES FOR TMS*

TEMPERATURE (°C)	R_T (ohms)
-2	6367
0	5806
2	5298
4	4840
6	4427
8	4053
10	3715
12	3412
14	3130
16	2880
18	2649
20	2441
22	2250
24	2077
26	1919
28	1774
30	1642

* Martek Model TMS Temperature Measuring System[10]

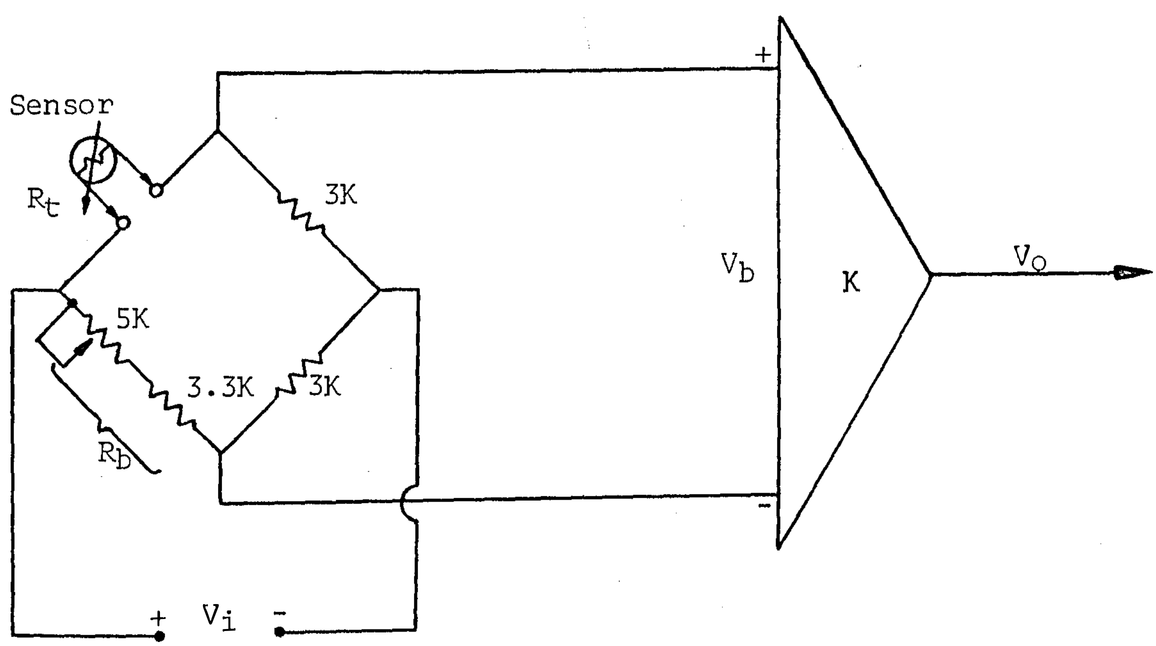


Figure 16. Simplified Temperature Sensor Circuit
(For range 8^oC - 20^oC)

Based on table 5, the following regression equation is obtained.

$$TEMP = 223.24588 + 0.14452 \times 10^{-6} R_t^2 - 0.12202 \times 10^{-14} R_t^4 - 26.158 \ln(R_t) \qquad (5\text{-}5)$$

Figure 17 shows the fit of the regression curve to the given data.

Equation (5-4) is then solved for $R_t = f(V_o)$ and this is substituted into equation (5-5). The result is $T = f(V_o)$. The accuracy and temperature range for this equation are tabulated below.

Accuracy	Range
± 0.072°F (0.04°C)	28 to 86°F

(b) Conductivity Cell:

Table 6 gives the relationship between output voltages and conductivity of the conductivity cell. Based on this table, the following regression equation is obtained.

$$C_d = 6.82388 - 13.715 E_a + 40.944 E_a^2 - 29.11 E_a^3 + 2.3178 \ln(E_a) \qquad (5\text{-}6)$$

Where C_d = conductivity

E_a = output voltage

The fit of the regression curve to the given data is shown in Figure 18. The accuracy and temperature range for this equation are tabulated below.

Accuracy	Range
± 0.015 mmho/cm	0 to 10 mmho/cm

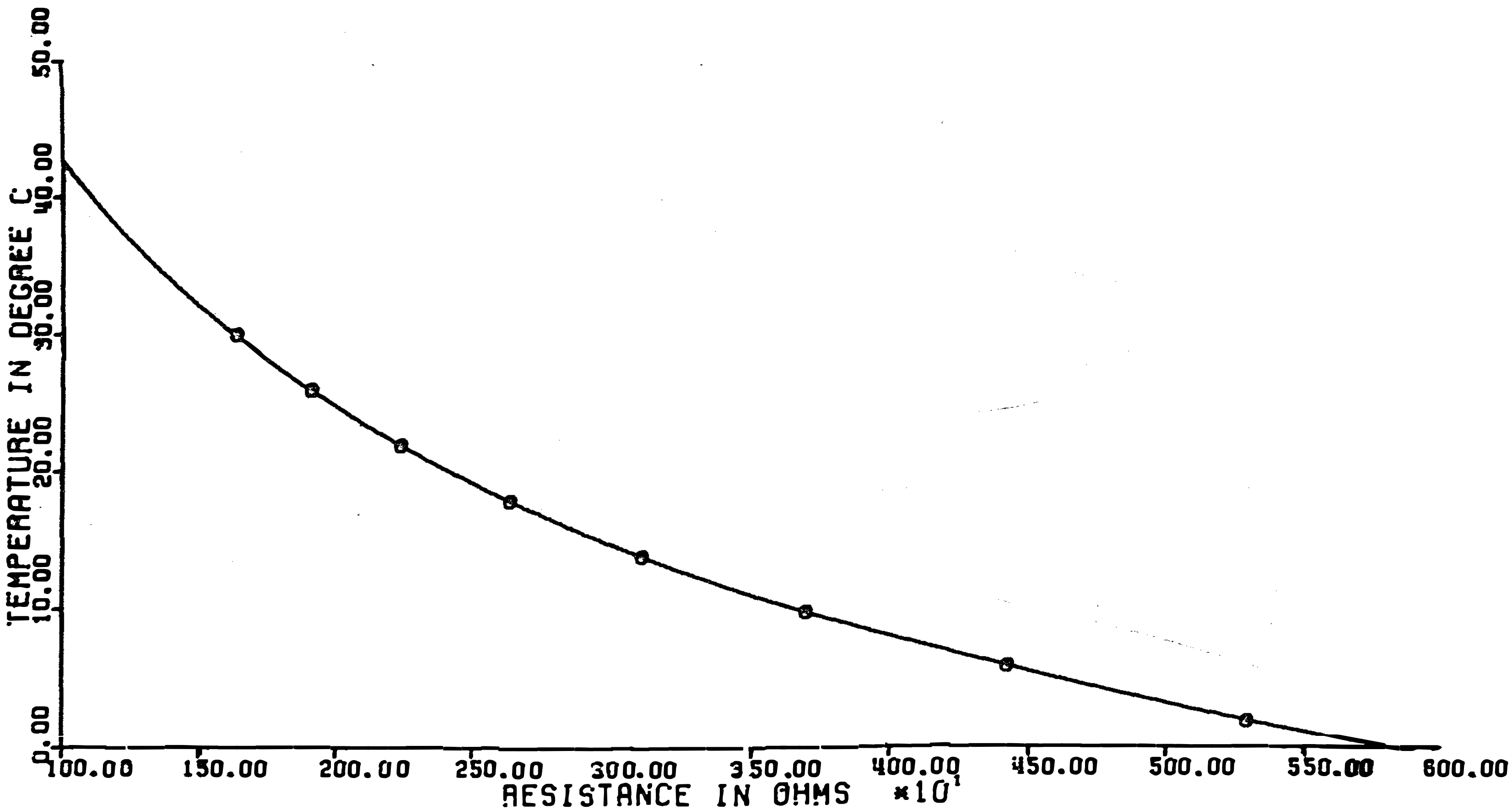


Figure 17. Temperature vs. Resistance for Martek Temperature Sensor

Table 6

CONDUCTIVITY VALUES FOR CMS *

Voltage (V)	Conductivity (mmho/cm)
0.074	0.
0.078	0.076
0.082	0.153
0.090	0.306
0.106	0.612
0.154	1.225
0.264	2.45
0.356	3.425
0.492	4.90
0.580	5.698
0.852	8.584
0.972	9.8

* Martek Model CMS In Situ Conductivity Monitor

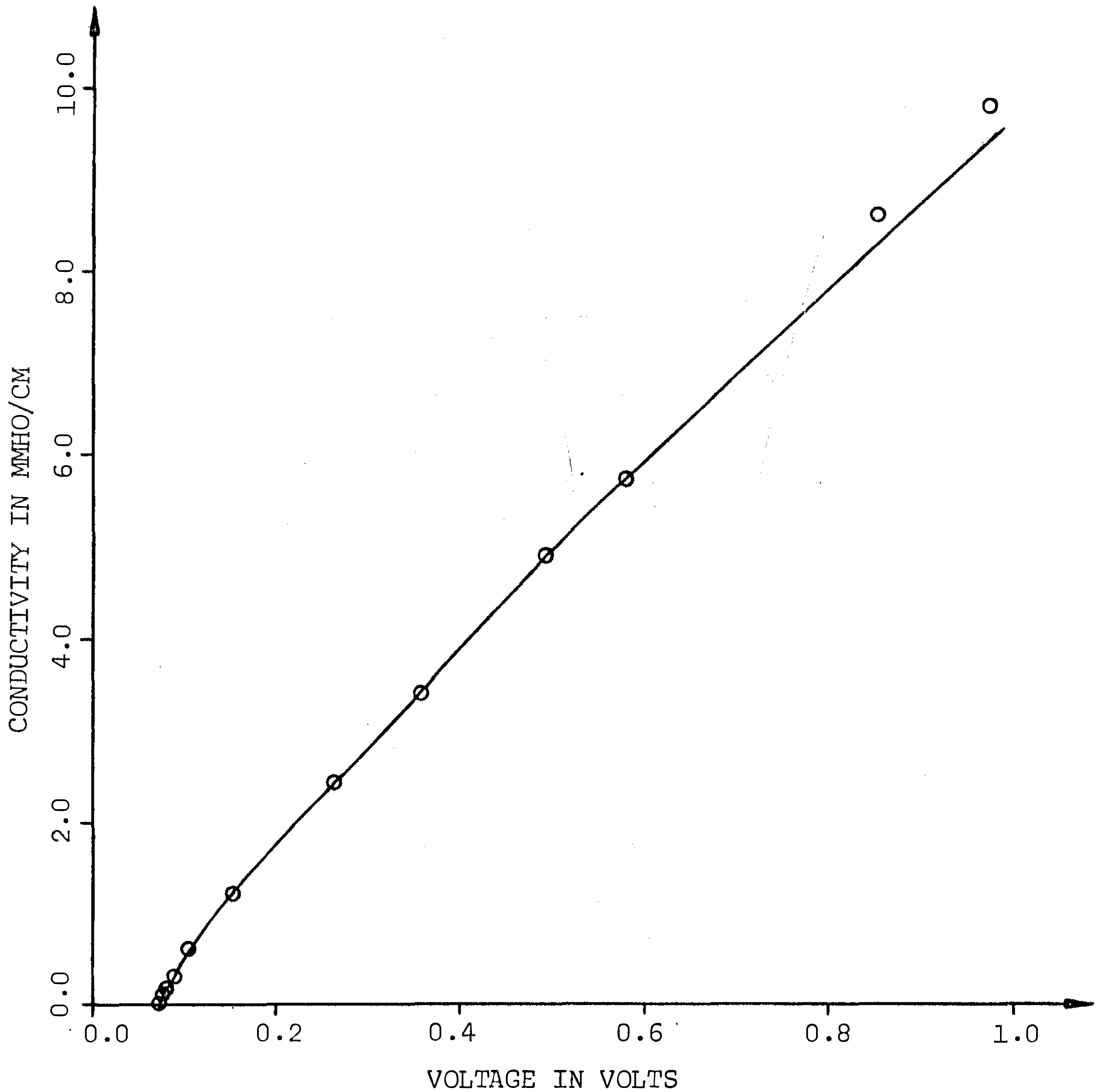


Figure 18. Conductivity versus voltage for Martek Temperature Sensor

Current Meter Data Conversion:

The theoretical relationship between voltage output and velocity input is a square law. The current meter was calibrated in a tow tank at NASA-Langley. Plots of output versus input for the x and y axis are shown in Figure 19. Error plots of the square law deviation are shown in figure 20. From these it is seen that the y axis indicates velocities up to 11 ft/sec and the x axis indicates velocities up to 6 ft/sec without appreciable error. The accuracy and range for the square law equation are tabulated below.

	Accuracy	Range
x axis	± .11 ft/sec	0 to 6 ft/sec
y axis	± .18 ft/sec	0 to 11 ft/sec

Total instrumentation errors of the moving boat system, considering all the information given above and combining it with the instrument measurement error, is shown below in Table 7.

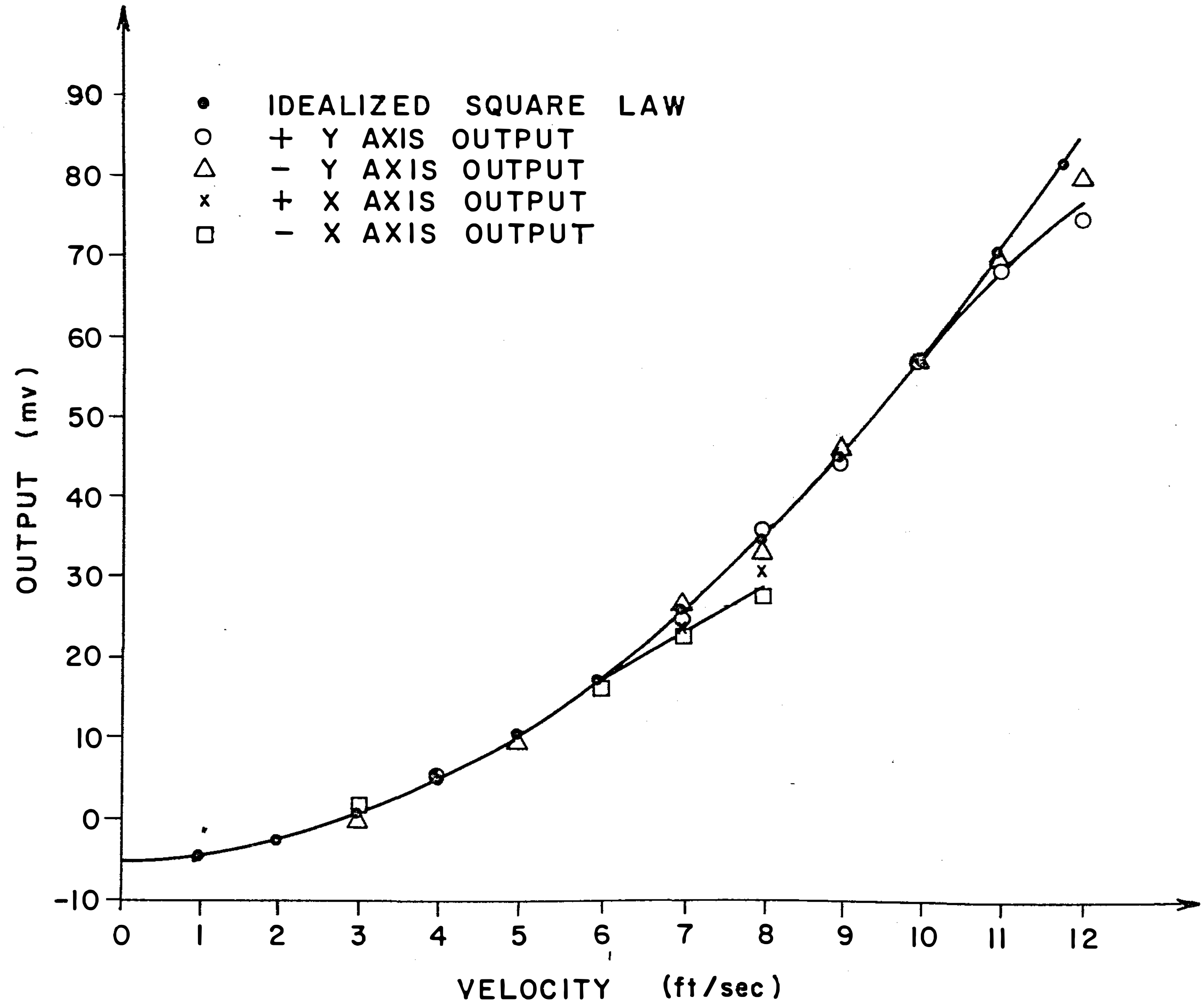
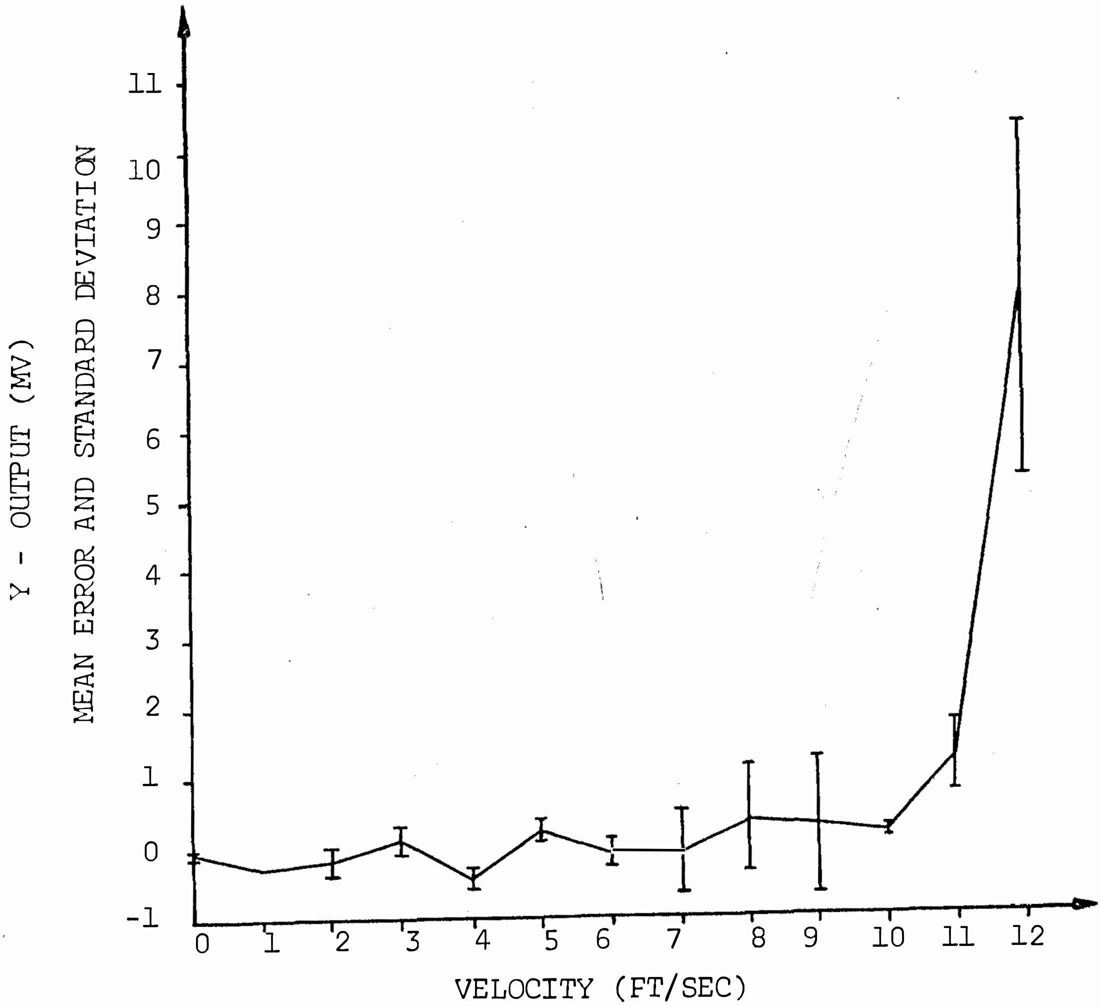


Figure 19. Plot of Drag Sphere Current Meter Output



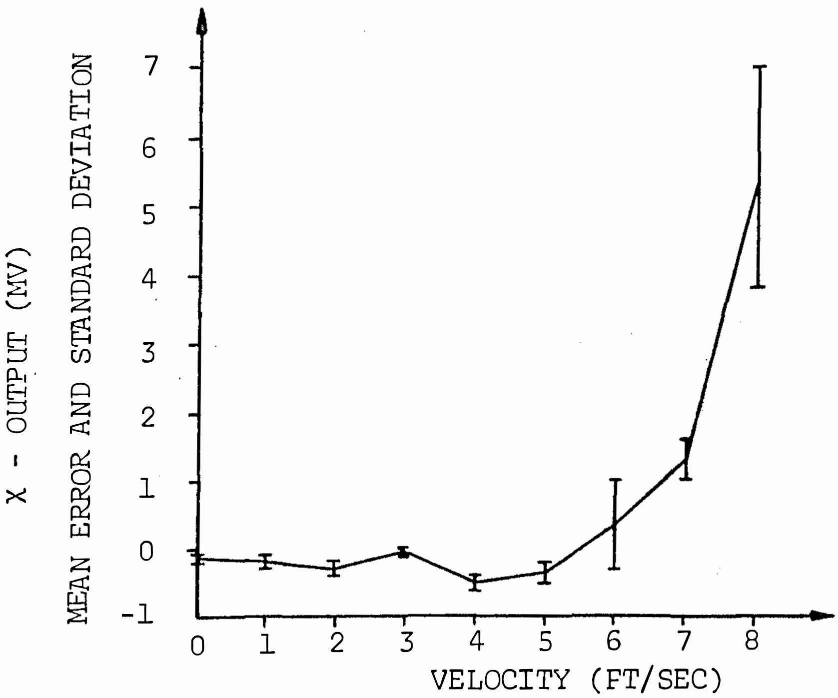


Figure 20. Plot of Drag Sphere Error Statistics

Table 7

Boat System Error

Instrument	Accuracy	Range
Water current meter		
x axis	± .11 ft/sec	0 to 6 ft/sec
y axis	± .18 ft/sec	0 to 11 ft/sec
Temperature profiler		
water thermistor	± 0.3°F	23 to 95°F
air thermistor	± 0.3°F	14 to 86°F
	± 0.35°F	86 to 104°F
EG&G dew point hygrometer	± 1.3°F	-40 to 122°F
Barnes infrared thermometer	± 0.75°F	20 to 100°F
Martek salinometer		
thermistor	± 0.672°F	28 to 86°F
	± 0.272°F	28 to 50°F
	± 0.272°F	46 to 68°F
	± 0.272°F	64 to 86°F
conductivity cell	± 0.115 mmho/cm	0 to 65 mmho/cm
	± 0.115 mmho/cm	0 to 10 mmho/cm
Raytheon fathometer	± 1.0 in	0 to 250 ft
Lundy heading indicator	± 1.°	0 to 360°

SYSTEM RESULTS

Raw data from two tide gauges on towers #1 and #7 and the moving boat system are now available. Data from the moving boat system were taken by following the path shown in figure 4.

Print out from the magnetic tape of the boat system appears on the next page. The first eight digit number in the left hand column of the sheet is the elapsed time in hundreths of minutes. Shown left to right after the elapsed time are data which enter through channels 1 to 10, then another eight digit number which is the external digital data, then data which enter through channels 11 to 20. The data recorded in each channel is identified above each column. This is raw voltage data and must be processed to obtain temperature, velocity, salinity, etc.

Data plotting is the subsequent step after conversion of voltages to physical parameters. The plots provide information which can be used to determine the best method for further processing and analysis. The information is:

1. signal content
2. normal pattern recognition
3. transformation suggestions
4. noise content
5. further analysis suggestions

Raw data plots of water and air temperatures for each transect at low slack water are shown in Appendix E.

```
                 WATER TEMPERATURE                      AIR TEMP.   POSI- CUR-         EXT.    CUR-             DEW                      SALINOMETER
ELAPSED                                                             TION  RENT         DIG.    RENT             POINT ZERO   VOLT
TIME     1/2'   3'    6'    9'   18'   24'              LOW   HIGH  MARK  SIDE         DATA    NORMAL  IRT      TEMP. REF.   REF.   TEMP. COND.
00000374-5023-5015-4996-0001+0002-0002-5367-5845-0006+2532   00000000+6071-4560-6470+0002-4155+4066+0810+0811+0905+0001
00000376-5038-5014-5002-0002+0002-0002-5374-5832-0006+2577   00000000+6211-4587-6486+0001-4155+4064+0797+0787+0888+0001
00000378-5029-5020-5007-0001+0002-0002-5371-5836-0006+2373   00000000+6067-4656-6514+0002-4155+4061+0767+0742+0848+0001
00000380-5042-5020-5006+0001+0002-0002-5384-5820-0006+2546   00000000+5963-4624-6555+0001-4155+4067+0813+0799+0899+0001
00000382-5044-5017-5003-0002+0002-0002-5375-5790-0006+2293   00000000+6049-4588-6593-0001-4155+4066+0787+0794+0893+0001
00000384-5040-5026-5006-0001+0002-0002-5389-5789-0006+2418   00000000+6297-4619-6623+0002-4155+4066+0791+0781+0880+0001
00000386-5039-5020-5005-0002+0002-0002-5390-5795-0006+2517   00000000+6108-4588-6673+0002-4155+4066+0804+0778+0878+0001
00000388-5027-5015-5004-0002+0002-0002-5376-5856-0007+2379   00000000+6481-4574-6717-0002-4156+4063+0788+0793+0894+0001
00000390-5026-5017-5002-0001+0002-0002-5349-5832-0006+2431   00000000+5915-4622-6764+0001-4155+4062+0841+0856+0947+0001
00000392-5047-5024-5013+0001+0002-0002-5384-5808-0007+2431   00000000+6133-4595-6782-0002-4155+4057+0766+0783+0884+0001
00000394-5039-5013-5002-0002+0002-0002-5371-5817-0006+2458   00000000+6055-4595-6764+0003-4154+4063+0821+0845+0941+0001
00000396-5014-5007-5003-0002+0002-0002-5366-5820-0006+2613   00000000+6027-4600-6693+0003-4154+4068+0789+0793+0891+0001
00000398-5046-5012-5000-0002+0002-0002-5362-5793-0007+2477   00000000+6303-4582-6579-0001-4155+4067+0808+0803+0901+0001
00000400-5029-5019-4999+0001+0002-0002-5369-5790-0005+2388   00000000+5945-4590-6466+0003-4154+4064+0792+0761+0862+0001
00000402-5026-5015-5004-0001+0002-0002-5344-5788-0006+2661   00000000+6400-4540-6378+0001-4155+4073+0801+0776+0876-0001
00000404-5035-5022-5013-0002+0002-0002-5390-5803-0007+2411   00000000+6190-4585-6346+0001-4155+4068+0782+0751+0851+0001
00000406-5009-5023-5006-0001+0002-0002-5400-5791-0006+2620   00000000+6212-4599-6352+0001-4155+4077+0794+0774+0872+0001
00000408-5040-5017-5004-0002+0002-0002-5369-5833-0007+2488   00000000+6023-4616-6386+0001-4155+4074+0789+0752+0852+0001
00000410-5027-5019-5006+0001+0003-0002-5374-5782-0006+2435   00000000+6312-4590-6429+0002-4155+4075+0761+0721+0826+0001
00000412-5048-5023-5009-0001+0002-0002-5353-5786-0006+2425   00000000+5916-4566-6467+0002-4155+4071+0805+0818+0912+0001
00000414-5059-5009-5002+0001+0002-0002-5361-5774-0006+2439   00000000+6078-4565-6502+0002-4153+4067+0797+0845+0933-0001
00000416-5050-5012-5009+0001+0002-0002-5364-5770-0006+2532   00000000+6223-4594-6553+0002-4155+4078+0791+0793+0887+0001
00000418-5049-5024-5004-0002+0002-0002-5355-5757-0005+2388   00000000+6409-4531-6602+0001-4155+4074+0814+0789+0885+0001
00000420-5048-5020-5004-0002+0002-0002-5328-5795-0007+2420   00000000+6504-4576-6597+0001-4155+4076+0798+0768+0866+0001
00000422-5022-5025-5007+0001+0002-0002-5361-5822-0006+2371   00000000+6418-4601-6569+0001-4155+4075+0793+0778+0874+0001
00000424-5029-5022-5003-0002+0002-0002-5326-5789-0007+2367   00000000+6082-4571-6495+0001-4155+4078+0783+0774+0871+0001
00000426-5026-5024-5009+0001+0002-0002-5329-5802-0005+2555   00000000+6272-4586-6406+0002-4154+4070+0796+0779+0877+0001
00000428-5013-5022-5006-0001+0002-0002-5328-5802-0006+2613   00000000+6386-4595-6335+0001-4154+4073+0802+0777+0868+0001
00000430-5019-5018-5006-0002+0002-0002-5339-5797-0007+2308   00000000+5755-4655-6316+0001-4155+4073+0802+0772+0868+0001
00000432-5017-5017-5004+0001+0002-0002-5348-5811-0004+2419   00000000+5742-4591-6325+0003-4154+4068+0798+0824+0912+0001
00000434-5010-5012-4998-0002+0002-0002-5353-5787-0006+2391   00000000+5963-4554-6368+0001-4155+4071+0792+0826+0918+0001
00000436-5012-5012-5004-0002+0002-0002-5358-5784-0006+2512   00000000+6264-4557-6404+0001-4155+4074+0808+0773+0873+0001
```

FUTURE WORK

All data are automatically recorded on tape, translated by computer, and will be published periodically. Pre-operational background data is being collected now. Surveys will continue at Surry Point after one nuclear generator unit is operational and, at a later date, after two nuclear generator units are operational.

The field data will be compared to model study temperature patterns[1] under similar wind and flow conditions obtained by Pritchard and Carpenter. Dr. Pritchard and Dr. Carpenter were VEPCO consultants who performed studies using the James River Hydraulic Model to predict waste heat distributions expected from the Surry Station. Their work resulted in approval by the Virginia State Water Control Board for construction of the facility. The correlation of field data to model data boundaries of excess temperature and surface thermal gradients in the plume will be computed. In a step beyond modeling capability, heat transfer coefficients will be computed. This work will be useful in verifying and improving present scientific techniques of predicting changes in estuaries due to similar industrial developments.

APPENDIX A

DETAILED SIGNAL FLOW DIAGRAM
OF INSTRUMENTS ABOARD THE INVESTIGATOR

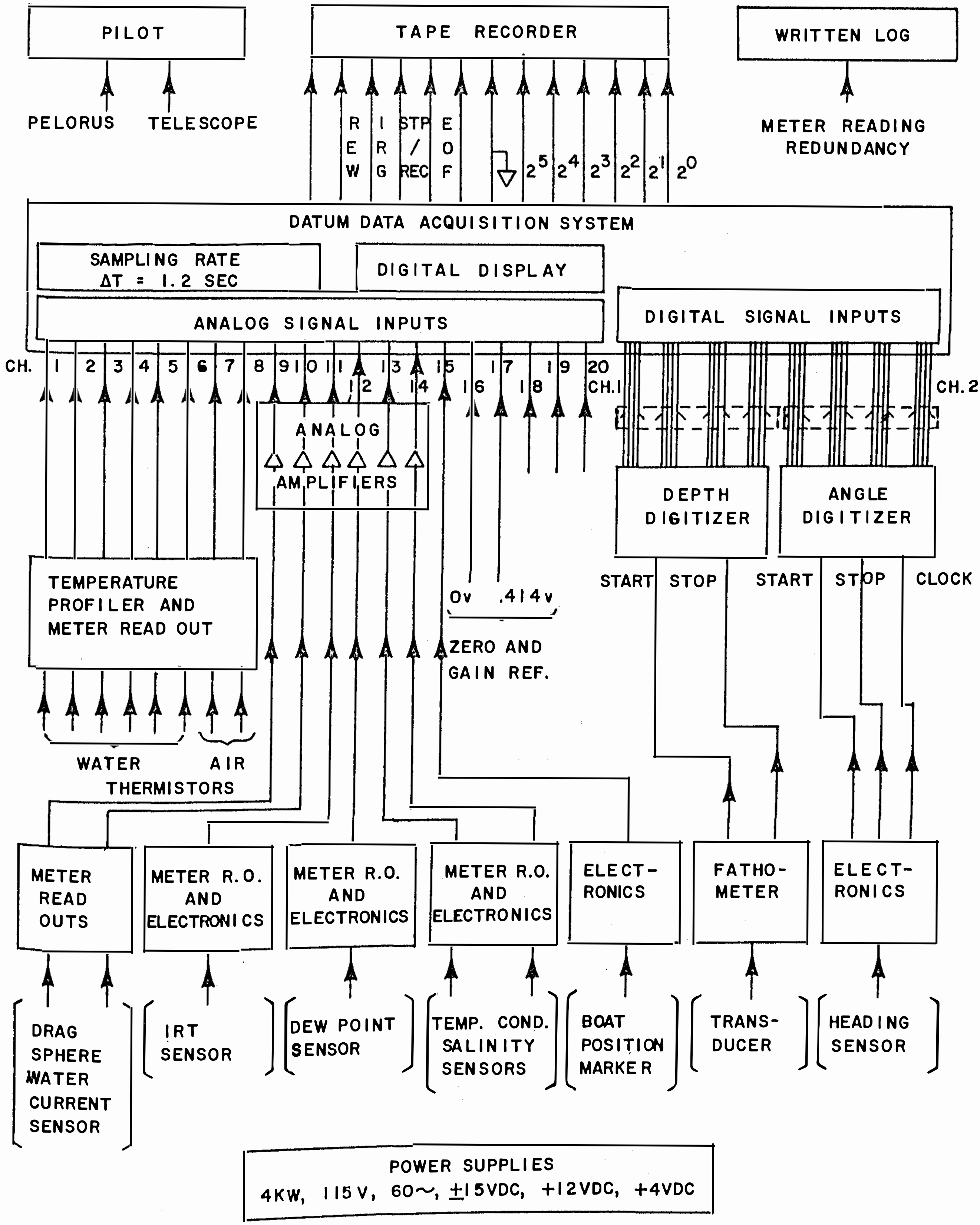


Figure 21. Instrument system on Investigator

APPENDIX B

TABLE OF TEMPERATURE vs. OHMS

AND VOLTAGE FOR THE THERMISTORS

USED IN THE TEMPERATURE PROFILER

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
0.1	32.1	11349.0	0.0004	0.0019	0.0038
0.2	32.3	11298.0	0.0008	0.0038	0.0076
0.3	32.5	11247.0	0.0013	0.0057	0.0115
0.4	32.7	11196.0	0.0017	0.0077	0.0154
0.5	32.9	11146.0	0.0021	0.0096	0.0192
0.6	33.0	11096.0	0.0026	0.0115	0.0231
0.7	33.2	11046.0	0.0030	0.0135	0.0270
0.8	33.4	10997.0	0.0034	0.0154	0.0308
0.9	33.6	10948.0	0.0039	0.0173	0.0347
1.0	33.8	10899.0	0.0043	0.0193	0.0386
1.1	33.9	10850.0	0.0048	0.0212	0.0425
1.2	34.1	10801.0	0.0052	0.0232	0.0465
1.3	34.3	10753.0	0.0056	0.0251	0.0503
1.4	34.5	10705.0	0.0061	0.0271	0.0543
1.5	34.7	10658.0	0.0065	0.0290	0.0581
1.6	34.8	10610.0	0.0070	0.0310	0.0621
1.7	35.0	10563.0	0.0074	0.0330	0.0660
1.8	35.2	10516.0	0.0079	0.0349	0.0699
1.9	35.4	10469.0	0.0083	0.0369	0.0739
2.0	35.6	10422.0	0.0088	0.0389	0.0779
2.1	35.7	10376.0	0.0092	0.0409	0.0818
2.2	35.9	10330.0	0.0096	0.0429	0.0858
2.3	36.1	10284.0	0.0101	0.0448	0.0897
2.4	36.3	10238.0	0.0106	0.0468	0.0937
2.5	36.5	10193.0	0.0110	0.0488	0.0977
2.6	36.6	10148.0	0.0114	0.0508	0.1016
2.7	36.8	10103.0	0.0119	0.0528	0.1056
2.8	37.0	10058.0	0.0124	0.0548	0.1097
2.9	37.2	10014.0	0.0128	0.0568	0.1136
3.0	37.4	9969.5	0.0133	0.0588	0.1176
3.1	37.5	9925.5	0.0137	0.0608	0.1216
3.2	37.7	9881.6	0.0142	0.0628	0.1257
3.3	37.9	9838.1	0.0146	0.0648	0.1297
3.4	38.1	9794.7	0.0151	0.0668	0.1337
3.5	38.3	9751.5	0.0155	0.0688	0.1377
3.6	38.4	9708.6	0.0160	0.0708	0.1417
3.7	38.6	9665.9	0.0164	0.0729	0.1458
3.8	38.8	9623.3	0.0169	0.0749	0.1498
3.9	39.0	9581.0	0.0173	0.0769	0.1539
4.0	39.2	9539.0	0.0178	0.0789	0.1579
4.1	39.3	9497.1	0.0183	0.0810	0.1620
4.2	39.5	9455.4	0.0187	0.0830	0.1660
4.3	39.7	9414.0	0.0192	0.0850	0.1701
4.4	39.9	9372.7	0.0196	0.0871	0.1742
4.5	40.1	9331.7	0.0201	0.0891	0.1782
4.6	40.2	9290.8	0.0206	0.0911	0.1823
4.7	40.4	9250.2	0.0210	0.0932	0.1864
4.8	40.6	9209.7	0.0215	0.0952	0.1905
4.9	40.8	9169.5	0.0220	0.0973	0.1946
5.0	41.0	9129.5	0.0224	0.0993	0.1987
5.1	41.1	9089.6	0.0229	0.1014	0.2028
5.2	41.3	9050.0	0.0233	0.1034	0.2069
5.3	41.5	9010.6	0.0238	0.1055	0.2110
5.4	41.7	8971.3	0.0243	0.1075	0.2151
5.5	41.9	8932.3	0.0247	0.1096	0.2192
5.6	42.0	8893.4	0.0252	0.1117	0.2234
5.7	42.2	8854.7	0.0257	0.1137	0.2275
5.8	42.4	8816.3	0.0261	0.1158	0.2316
5.9	42.6	8778.0	0.0266	0.1179	0.2358
6.0	42.8	8739.9	0.0271	0.1199	0.2399
6.1	42.9	8702.0	0.0275	0.1220	0.2440
6.2	43.1	8664.3	0.0280	0.1241	0.2482
6.3	43.3	8626.8	0.0285	0.1261	0.2523
6.4	43.5	8589.4	0.0289	0.1282	0.2565
6.5	43.7	8552.2	0.0294	0.1303	0.2607
6.6	43.8	8515.3	0.0299	0.1324	0.2648
6.7	44.0	8478.5	0.0304	0.1345	0.2690
6.8	44.2	8441.9	0.0308	0.1366	0.2732
6.9	44.4	8405.4	0.0313	0.1387	0.2774
7.0	44.6	8369.2	0.0318	0.1407	0.2815
7.1	44.7	8333.1	0.0323	0.1428	0.2857
7.2	44.9	8297.2	0.0327	0.1449	0.2899
7.3	45.1	8261.5	0.0332	0.1470	0.2941
7.4	45.3	8225.9	0.0337	0.1491	0.2983
7.5	45.5	8190.5	0.0341	0.1512	0.3025
7.6	45.6	8155.3	0.0346	0.1533	0.3067
7.7	45.8	8120.3	0.0351	0.1554	0.3109
7.8	46.0	8085.5	0.0356	0.1575	0.3151
7.9	46.2	8050.8	0.0361	0.1596	0.3193
8.0	46.4	8016.3	0.0365	0.1618	0.3236
8.1	46.5	7981.9	0.0370	0.1639	0.3278
8.2	46.7	7947.7	0.0375	0.1660	0.3320
8.3	46.9	7913.7	0.0380	0.1681	0.3362
8.4	47.1	7879.9	0.0384	0.1702	0.3405
8.5	47.3	7846.2	0.0389	0.1723	0.3447
8.6	47.4	7812.7	0.0394	0.1744	0.3489
8.7	47.6	7779.3	0.0399	0.1766	0.3532
8.8	47.8	7746.1	0.0404	0.1787	0.3574
8.9	48.0	7713.1	0.0408	0.1808	0.3617
9.0	48.2	7680.2	0.0413	0.1829	0.3659
9.1	48.3	7647.5	0.0418	0.1851	0.3702
9.2	48.5	7614.9	0.0423	0.1872	0.3744
9.3	48.7	7582.6	0.0428	0.1893	0.3787
9.4	48.9	7550.3	0.0432	0.1915	0.3830
9.5	49.1	7518.2	0.0437	0.1936	0.3872
9.6	49.2	7486.3	0.0442	0.1957	0.3915
9.7	49.4	7454.5	0.0447	0.1979	0.3958
9.8	49.6	7422.9	0.0452	0.2000	0.4001
9.9	49.8	7391.5	0.0457	0.2021	0.4043
10.0	50.0	7360.1	0.0461	0.2043	0.4086

Table 8

Profiler temperature vs. ohms and volts

Table 8 (cont'd)

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
10.1	50.1	7329.0	0.0466	0.2064	0.4129
10.2	50.3	7298.0	0.0471	0.2086	0.4172
10.3	50.5	7267.1	0.0476	0.2107	0.4215
10.4	50.7	7236.4	0.0481	0.2129	0.4258
10.5	50.9	7205.8	0.0486	0.2150	0.4301
10.6	51.0	7175.4	0.0491	0.2172	0.4344
10.7	51.2	7145.1	0.0495	0.2193	0.4387
10.8	51.4	7115.0	0.0500	0.2215	0.4430
10.9	51.6	7085.0	0.0505	0.2236	0.4473
11.0	51.8	7055.2	0.0510	0.2258	0.4516
11.1	51.9	7025.5	0.0515	0.2279	0.4559
11.2	52.1	6996.0	0.0520	0.2301	0.4602
11.3	52.3	6966.6	0.0525	0.2322	0.4645
11.4	52.5	6937.3	0.0530	0.2344	0.4688
11.5	52.7	6908.2	0.0534	0.2366	0.4732
11.6	52.8	6879.2	0.0539	0.2387	0.4775
11.7	53.0	6850.3	0.0544	0.2409	0.4818
11.8	53.2	6821.6	0.0549	0.2430	0.4861
11.9	53.4	6793.0	0.0554	0.2452	0.4905
12.0	53.6	6764.6	0.0559	0.2474	0.4948
12.1	53.7	6736.3	0.0564	0.2495	0.4991
12.2	53.9	6708.1	0.0569	0.2517	0.5035
12.3	54.1	6680.1	0.0574	0.2539	0.5078
12.4	54.3	6652.2	0.0578	0.2560	0.5121
12.5	54.5	6624.4	0.0583	0.2582	0.5165
12.6	54.6	6596.8	0.0588	0.2604	0.5208
12.7	54.8	6569.3	0.0593	0.2626	0.5252
12.8	55.0	6541.9	0.0598	0.2647	0.5295
12.9	55.2	6514.7	0.0603	0.2669	0.5339
13.0	55.4	6487.6	0.0608	0.2691	0.5382
13.1	55.5	6460.6	0.0613	0.2713	0.5426
13.2	55.7	6433.7	0.0618	0.2734	0.5469
13.3	55.9	6407.0	0.0623	0.2756	0.5513
13.4	56.1	6380.4	0.0628	0.2778	0.5556
13.5	56.3	6353.9	0.0633	0.2800	0.5600
13.6	56.4	6327.6	0.0637	0.2822	0.5644
13.7	56.6	6301.4	0.0642	0.2843	0.5687
13.8	56.8	6275.3	0.0647	0.2865	0.5731
13.9	57.0	6249.3	0.0652	0.2887	0.5774
14.0	57.2	6223.4	0.0657	0.2909	0.5818
14.1	57.3	6197.7	0.0662	0.2931	0.5862
14.2	57.5	6172.1	0.0667	0.2952	0.5905
14.3	57.7	6146.6	0.0672	0.2974	0.5949
14.4	57.9	6121.2	0.0677	0.2996	0.5993
14.5	58.1	6096.0	0.0682	0.3018	0.6037
14.6	58.2	6070.9	0.0687	0.3040	0.6080
14.7	58.4	6045.9	0.0692	0.3062	0.6124
14.8	58.6	6021.0	0.0697	0.3084	0.6168
14.9	58.8	5996.2	0.0702	0.3106	0.6212
15.0	59.0	5971.5	0.0707	0.3127	0.6255

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
15.1	59.1	5947.0	0.0712	0.3149	0.6299
15.2	59.3	5922.5	0.0717	0.3171	0.6343
15.3	59.5	5898.2	0.0721	0.3193	0.6387
15.4	59.7	5874.0	0.0726	0.3215	0.6431
15.5	59.9	5849.9	0.0731	0.3237	0.6475
15.6	60.0	5826.0	0.0736	0.3259	0.6518
15.7	60.2	5802.1	0.0741	0.3281	0.6562
15.8	60.4	5778.4	0.0746	0.3303	0.6606
15.9	60.6	5754.7	0.0751	0.3325	0.6650
16.0	60.8	5731.2	0.0756	0.3347	0.6694
16.1	60.9	5707.8	0.0761	0.3368	0.6737
16.2	61.1	5684.5	0.0766	0.3390	0.6781
16.3	61.3	5661.3	0.0771	0.3412	0.6825
16.4	61.5	5638.2	0.0776	0.3434	0.6869
16.5	61.7	5615.2	0.0781	0.3456	0.6913
16.6	61.8	5592.3	0.0786	0.3478	0.6957
16.7	62.0	5569.5	0.0791	0.3500	0.7001
16.8	62.2	5546.9	0.0796	0.3522	0.7045
16.9	62.4	5524.3	0.0801	0.3544	0.7089
17.0	62.6	5501.8	0.0806	0.3566	0.7133
17.1	62.7	5479.5	0.0811	0.3588	0.7176
17.2	62.9	5457.2	0.0816	0.3610	0.7221
17.3	63.1	5435.1	0.0821	0.3632	0.7264
17.4	63.3	5413.1	0.0826	0.3654	0.7308
17.5	63.5	5391.1	0.0831	0.3676	0.7352
17.6	63.6	5369.3	0.0836	0.3698	0.7396
17.7	63.8	5347.5	0.0841	0.3720	0.7440
17.8	64.0	5325.9	0.0845	0.3742	0.7484
17.9	64.2	5304.4	0.0850	0.3764	0.7528
18.0	64.4	5282.9	0.0855	0.3786	0.7572
18.1	64.5	5261.6	0.0860	0.3808	0.7616
18.2	64.7	5240.4	0.0865	0.3830	0.7660
18.3	64.9	5219.2	0.0870	0.3852	0.7704
18.4	65.1	5198.2	0.0875	0.3873	0.7747
18.5	65.3	5177.2	0.0880	0.3895	0.7791
18.6	65.4	5156.4	0.0885	0.3917	0.7835
18.7	65.6	5135.6	0.0890	0.3939	0.7879
18.8	65.8	5115.0	0.0895	0.3961	0.7923
18.9	66.0	5094.4	0.0900	0.3983	0.7967
19.0	66.2	5073.9	0.0905	0.4005	0.8011
19.1	66.3	5053.6	0.0910	0.4027	0.8055
19.2	66.5	5033.3	0.0915	0.4049	0.8099
19.3	66.7	5013.1	0.0920	0.4071	0.8142
19.4	66.9	4993.0	0.0925	0.4093	0.8186
19.5	67.1	4973.0	0.0930	0.4115	0.8230
19.6	67.2	4953.1	0.0935	0.4137	0.8274
19.7	67.4	4933.3	0.0940	0.4159	0.8318
19.8	67.6	4913.5	0.0945	0.4181	0.8362
19.9	67.8	4893.9	0.0950	0.4203	0.8406
20.0	68.0	4874.4	0.0955	0.4224	0.8449

Table 8 (Cont'd)

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
20.1	68.1	4854.9	0.0960	0.4246	0.8493
20.2	68.3	4835.5	0.0965	0.4268	0.8537
20.3	68.5	4816.3	0.0969	0.4290	0.8581
20.4	68.7	4797.1	0.0974	0.4312	0.8624
20.5	68.9	4778.0	0.0979	0.4334	0.8668
20.6	69.0	4758.9	0.0984	0.4356	0.8712
20.7	69.2	4740.0	0.0989	0.4378	0.8756
20.8	69.4	4721.2	0.0994	0.4400	0.8800
20.9	69.6	4702.4	0.0999	0.4421	0.8843
21.0	69.8	4683.7	0.1004	0.4443	0.8887
21.1	69.9	4665.1	0.1009	0.4465	0.8931
21.2	70.1	4646.6	0.1014	0.4487	0.8975
21.3	70.3	4628.2	0.1019	0.4509	0.9018
21.4	70.5	4609.9	0.1024	0.4531	0.9062
21.5	70.7	4591.6	0.1029	0.4553	0.9106
21.6	70.8	4573.4	0.1034	0.4574	0.9149
21.7	71.0	4555.3	0.1039	0.4596	0.9193
21.8	71.2	4537.3	0.1044	0.4618	0.9237
21.9	71.4	4519.4	0.1049	0.4640	0.9280
22.0	71.6	4501.6	0.1053	0.4662	0.9324
22.1	71.7	4483.8	0.1058	0.4683	0.9367
22.2	71.9	4466.1	0.1063	0.4705	0.9411
22.3	72.1	4448.5	0.1068	0.4727	0.9454
22.4	72.3	4431.0	0.1073	0.4749	0.9498
22.5	72.5	4413.5	0.1078	0.4771	0.9542
22.6	72.6	4396.2	0.1083	0.4792	0.9585
22.7	72.8	4378.9	0.1088	0.4814	0.9628
22.8	73.0	4361.7	0.1093	0.4836	0.9672
22.9	73.2	4344.6	0.1098	0.4857	0.9715
23.0	73.4	4327.5	0.1103	0.4879	0.9759
23.1	73.5	4310.5	0.1108	0.4901	0.9802
23.2	73.7	4293.6	0.1112	0.4923	0.9846
23.3	73.9	4276.8	0.1117	0.4944	0.9889
23.4	74.1	4260.0	0.1122	0.4966	0.9932
23.5	74.3	4243.4	0.1127	0.4987	0.9975
23.6	74.4	4226.8	0.1132	0.5009	1.0019
23.7	74.6	4210.2	0.1137	0.5031	1.0062
23.8	74.8	4193.8	0.1142	0.5052	1.0105
23.9	75.0	4177.4	0.1147	0.5074	1.0149
24.0	75.2	4161.1	0.1152	0.5096	1.0192
24.1	75.3	4144.9	0.1156	0.5117	1.0235
24.2	75.5	4128.7	0.1161	0.5139	1.0278
24.3	75.7	4112.6	0.1166	0.5161	1.0322
24.4	75.9	4096.6	0.1171	0.5182	1.0365
24.5	76.1	4080.7	0.1176	0.5204	1.0408
24.6	76.2	4064.8	0.1181	0.5225	1.0451
24.7	76.4	4049.0	0.1186	0.5247	1.0494
24.8	76.6	4033.3	0.1191	0.5268	1.0537
24.9	76.8	4017.6	0.1195	0.5290	1.0580
25.0	77.0	4002.0	0.1200	0.5311	1.0623
25.1	77.1	3986.5	0.1205	0.5333	1.0666
25.2	77.3	3971.0	0.1210	0.5354	1.0709
25.3	77.5	3955.6	0.1215	0.5376	1.0752
25.4	77.7	3940.3	0.1220	0.5397	1.0795
25.5	77.9	3925.1	0.1225	0.5419	1.0838
25.6	78.0	3909.9	0.1229	0.5440	1.0880
25.7	78.2	3894.8	0.1234	0.5461	1.0923
25.8	78.4	3879.7	0.1239	0.5483	1.0966
25.9	78.6	3864.8	0.1244	0.5504	1.1009
26.0	78.8	3849.9	0.1249	0.5525	1.1051
26.1	78.9	3835.0	0.1254	0.5547	1.1094
26.2	79.1	3820.2	0.1258	0.5568	1.1137
26.3	79.3	3805.5	0.1263	0.5590	1.1180
26.4	79.5	3790.9	0.1268	0.5611	1.1222
26.5	79.7	3776.3	0.1273	0.5632	1.1265
26.6	79.8	3761.8	0.1278	0.5653	1.1307
26.7	80.0	3747.3	0.1282	0.5675	1.1350
26.8	80.2	3732.9	0.1287	0.5696	1.1392
26.9	80.4	3718.6	0.1292	0.5717	1.1435
27.0	80.6	3704.3	0.1297	0.5738	1.1477
27.1	80.7	3690.1	0.1302	0.5760	1.1520
27.2	80.9	3676.0	0.1306	0.5781	1.1562
27.3	81.1	3661.9	0.1311	0.5802	1.1605
27.4	81.3	3647.9	0.1316	0.5823	1.1647
27.5	81.5	3633.9	0.1321	0.5844	1.1689
27.6	81.6	3620.0	0.1326	0.5865	1.1731
27.7	81.8	3606.2	0.1330	0.5887	1.1774
27.8	82.0	3592.4	0.1335	0.5908	1.1816
27.9	82.2	3578.7	0.1340	0.5929	1.1858
28.0	82.4	3565.1	0.1345	0.5950	1.1900
28.1	82.5	3551.5	0.1349	0.5971	1.1942
28.2	82.7	3537.9	0.1354	0.5992	1.1984
28.3	82.9	3524.5	0.1359	0.6013	1.2026
28.4	83.1	3511.1	0.1364	0.6034	1.2068
28.5	83.3	3497.7	0.1368	0.6055	1.2110
28.6	83.4	3484.4	0.1373	0.6076	1.2152
28.7	83.6	3471.2	0.1378	0.6097	1.2194
28.8	83.8	3458.0	0.1383	0.6118	1.2236
28.9	84.0	3444.9	0.1387	0.6139	1.2278
29.0	84.2	3431.8	0.1392	0.6159	1.2319
29.1	84.3	3418.8	0.1397	0.6180	1.2361
29.2	84.5	3405.9	0.1401	0.6201	1.2403
29.3	84.7	3393.0	0.1406	0.6222	1.2444
29.4	84.9	3380.1	0.1411	0.6243	1.2486
29.5	85.1	3367.3	0.1416	0.6264	1.2528
29.6	85.2	3354.6	0.1420	0.6284	1.2569
29.7	85.4	3341.9	0.1425	0.6305	1.2611
29.8	85.6	3329.3	0.1430	0.6326	1.2652
29.9	85.8	3316.8	0.1434	0.6347	1.2694
30.0	86.0	3304.3	0.1439	0.6367	1.2735

Table 8 (Cont'd)

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
30.1	86.1	3291.8	0.1444	0.6388	1.2777
30.2	86.3	3279.4	0.1448	0.6409	1.2818
30.3	86.5	3267.1	0.1453	0.6429	1.2859
30.4	86.7	3254.8	0.1458	0.6450	1.2900
30.5	86.9	3242.5	0.1462	0.6471	1.2942
30.6	87.0	3230.3	0.1467	0.6491	1.2983
30.7	87.2	3218.2	0.1472	0.6512	1.3024
30.8	87.4	3206.1	0.1476	0.6532	1.3065
30.9	87.6	3194.1	0.1481	0.6553	1.3106
31.0	87.8	3182.1	0.1486	0.6573	1.3147
31.1	87.9	3170.2	0.1490	0.6594	1.3188
31.2	88.1	3158.3	0.1495	0.6614	1.3229
31.3	88.3	3146.5	0.1500	0.6635	1.3270
31.4	88.5	3134.7	0.1504	0.6655	1.3311
31.5	88.7	3123.0	0.1509	0.6676	1.3352
31.6	88.8	3111.4	0.1513	0.6696	1.3392
31.6	88.8	3099.7	0.1518	0.6716	1.3433
31.8	89.2	3088.2	0.1523	0.6737	1.3474
31.9	89.4	3076.7	0.1527	0.6757	1.3514
32.0	89.6	3065.2	0.1532	0.6777	1.3555
32.1	89.7	3053.8	0.1536	0.6797	1.3595
32.2	89.9	3042.4	0.1541	0.6818	1.3636
32.3	90.1	3031.1	0.1545	0.6838	1.3676
32.4	90.3	3019.8	0.1550	0.6858	1.3717
32.5	90.5	3008.6	0.1555	0.6878	1.3757
32.6	90.6	2997.4	0.1559	0.6898	1.3797
32.7	90.8	2986.3	0.1564	0.6919	1.3838
32.8	91.0	2975.2	0.1568	0.6939	1.3878
32.9	91.2	2964.2	0.1573	0.6959	1.3918
33.0	91.4	2953.2	0.1577	0.6979	1.3958
33.1	91.5	2942.2	0.1582	0.6999	1.3998
33.2	91.7	2931.3	0.1586	0.7019	1.4039
33.3	91.9	2920.5	0.1591	0.7039	1.4078
33.4	92.1	2909.7	0.1595	0.7059	1.4118
33.5	92.3	2898.9	0.1600	0.7079	1.4158
33.6	92.4	2888.2	0.1604	0.7099	1.4198
33.7	92.6	2877.6	0.1609	0.7119	1.4238
33.8	92.8	2867.0	0.1613	0.7139	1.4278
33.9	93.0	2856.4	0.1618	0.7158	1.4317
34.0	93.2	2845.9	0.1622	0.7178	1.4357
34.1	93.3	2835.4	0.1627	0.7198	1.4397
34.2	93.5	2824.9	0.1631	0.7218	1.4436
34.3	93.7	2814.6	0.1636	0.7238	1.4476
34.4	93.9	2804.2	0.1640	0.7257	1.4515
34.5	94.1	2793.9	0.1645	0.7277	1.4555
34.6	94.2	2783.6	0.1649	0.7297	1.4594
34.7	94.4	2773.4	0.1654	0.7317	1.4634
34.8	94.6	2763.2	0.1658	0.7336	1.4673
34.9	94.8	2753.1	0.1663	0.7356	1.4712
35.0	95.0	2743.0	0.1667	0.7375	1.4751

TEMC	TEMF	OHM	EBRI	EAMP	IOUT
35.1	95.1	2733.0	0.1671	0.7395	1.4790
35.2	95.3	2723.0	0.1676	0.7414	1.4829
35.3	95.5	2713.0	0.1680	0.7434	1.4869
35.4	95.7	2703.1	0.1685	0.7454	1.4908
35.5	95.9	2693.2	0.1689	0.7473	1.4947
35.6	96.0	2683.4	0.1693	0.7492	1.4985
35.7	96.2	2673.6	0.1698	0.7512	1.5024
35.8	96.4	2663.9	0.1702	0.7531	1.5063
35.9	96.6	2654.2	0.1707	0.7550	1.5101
36.0	96.8	2644.5	0.1711	0.7570	1.5140
36.1	96.9	2634.9	0.1715	0.7589	1.5179
36.2	97.1	2625.3	0.1720	0.7608	1.5217
36.3	97.3	2615.7	0.1724	0.7628	1.5256
36.4	97.5	2606.2	0.1728	0.7647	1.5295
36.5	97.7	2596.8	0.1733	0.7666	1.5333
36.6	97.8	2587.3	0.1737	0.7686	1.5372
36.7	98.0	2577.9	0.1741	0.7705	1.5410
36.8	98.2	2568.6	0.1746	0.7724	1.5448
36.9	98.4	2559.3	0.1750	0.7743	1.5486
37.0	98.6	2550.0	0.1754	0.7762	1.5524
37.1	98.7	2540.8	0.1759	0.7781	1.5562
37.2	98.9	2531.6	0.1763	0.7800	1.5601
37.3	99.1	2522.4	0.1767	0.7819	1.5639
37.4	99.3	2513.3	0.1772	0.7838	1.5677
37.5	99.5	2504.2	0.1776	0.7857	1.5715
37.6	99.6	2495.2	0.1780	0.7876	1.5752
37.7	99.8	2486.2	0.1784	0.7895	1.5790
37.8	100.0	2477.2	0.1789	0.7914	1.5828
37.9	100.2	2468.3	0.1793	0.7933	1.5866
38.0	100.4	2459.4	0.1797	0.7951	1.5903
38.1	100.5	2450.6	0.1801	0.7970	1.5941
38.2	100.7	2441.8	0.1806	0.7989	1.5978
38.3	100.9	2433.0	0.1810	0.8008	1.6016
38.4	101.1	2424.3	0.1814	0.8026	1.6053
38.5	101.3	2415.5	0.1818	0.8045	1.6091
38.6	101.4	2406.9	0.1823	0.8064	1.6128
38.7	101.6	2398.2	0.1827	0.8082	1.6165
38.8	101.8	2389.7	0.1831	0.8101	1.6202
38.9	102.0	2381.1	0.1835	0.8119	1.6239
39.0	102.2	2372.6	0.1839	0.8138	1.6276
39.1	102.3	2364.1	0.1844	0.8156	1.6313
39.2	102.5	2355.6	0.1848	0.8175	1.6351
39.3	102.7	2347.2	0.1852	0.8193	1.6387
39.4	102.9	2338.8	0.1856	0.8212	1.6424
39.5	103.1	2330.5	0.1860	0.8230	1.6461
39.6	103.2	2322.2	0.1864	0.8249	1.6498
39.7	103.4	2313.9	0.1869	0.8267	1.6534
39.8	103.6	2305.6	0.1873	0.8285	1.6571
39.9	103.8	2297.4	0.1877	0.8304	1.6608
40.0	104.0	2289.3	0.1881	0.8322	1.6644

APPENDIX C

DETAILED SIGNAL FLOW DIAGRAM

OF INSTRUMENTS ON TOWER #6

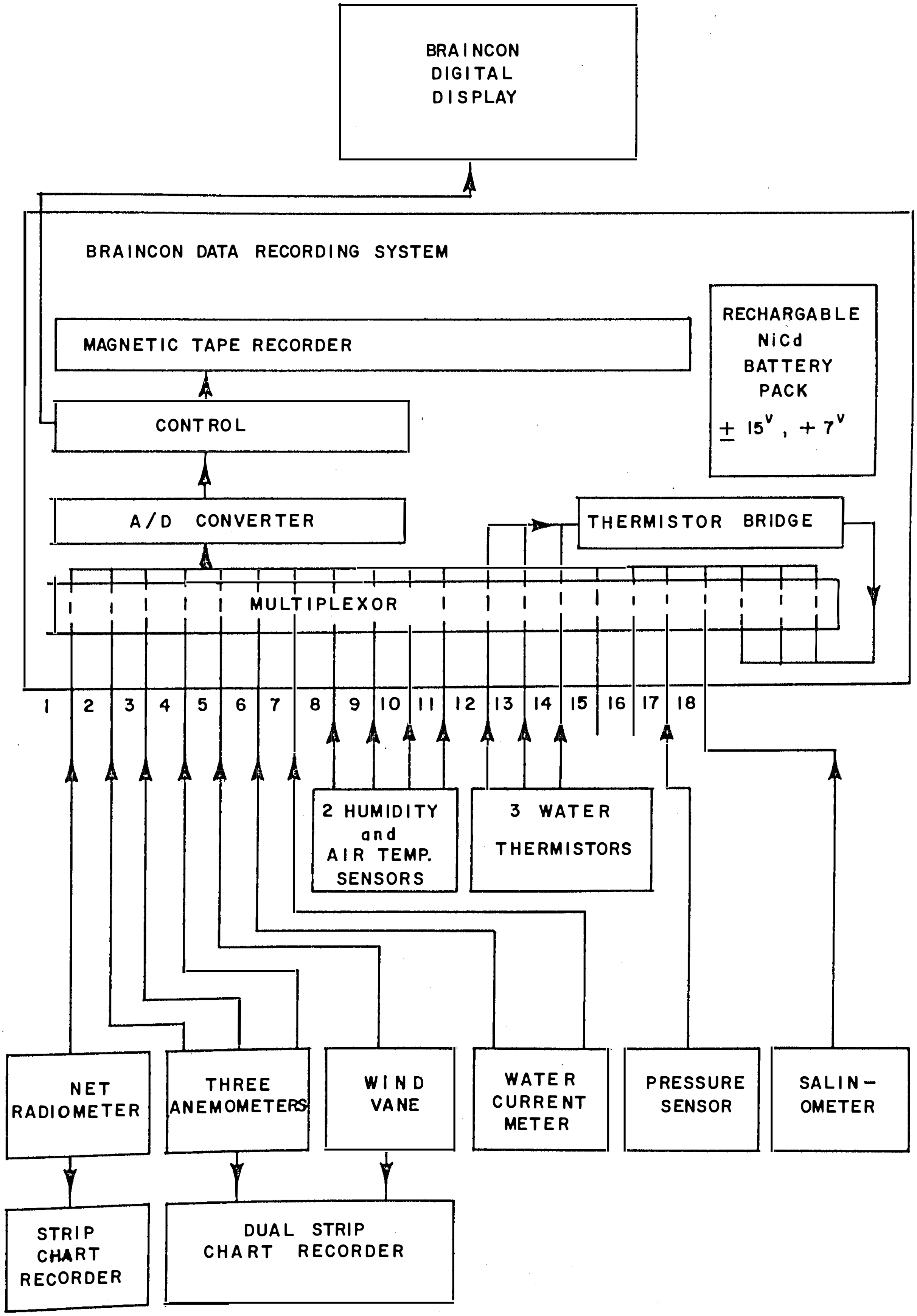


Figure 22. Instrument System on Tower #6

APPENDIX D

TABLE OF INSTRUMENTS, SENSORS AND ACCURACIES

Instrument	Sensor	Accuracy	Resolution	Range	Time Response
water current meter	strain gauge	x-axis $\pm$ .11 ft/sec y-axis $\pm$ .18 ft/sec	.01 ft/sec	0 to 6 ft/sec 0 to 11 ft/sec	
Thornwaite net radiometer recorded on chart	thermopile	dependent on calibrating standard voltage	.02 ly/min	-.4 to 1.6 ly/min	
recorded on magnetic tape			.01 ly/min	-.4 to 1.6 ly/min	
Weather Measure anemometer recorded on chart	cup type with high frequency tachometer	larger of 1% or .15 mph	.25 mph	0 to 50 mph	distance constant 6 ft.
recorded on magnetic tape		larger of 1% or .15 mph	.05 mph	0 to 50 mph	
Weather Measure wind direction recorded on chart	vane with potentiometer	$\pm 1^{\circ}$	2.5°	0° to 540°	distance constant 3.5 ft.
recorded on magnetic tape		$\pm 1^{\circ}$	$.5^{\circ}$	0° to 540°	
Thunder Scientific relative humidity meter	crystal	$\pm$ 2% RH	.1% RH	< 5% to 100% RH	.75 sec/10% RH charge
Barnes infra-red thermometer	thermistor bolometer	$\pm .75^{\circ}$F	$.08^{\circ}$F	20°F to 100°F	.5 sec
temperature profiler	water thermistor	$\pm .2^{\circ}$F	$.1^{\circ}$F	23°F to 95°F	.4 sec/still water
	air thermistor	$\pm .2^{\circ}$F	$.1^{\circ}$F	14°F to 104°F	1 sec/still air

Table 9

Instrument Specifications

Instrument	Sensor	Accuracy	Resolution	Range	Time Response
Martek salinometer	thermistor	± .6°F	.06°F	28°F to 86°F	1 sec
		± .2°F	.02°F	28°F to 50°F	1 sec
		± .2°F	.02°F	46°F to 68°F	1 sec
		± .2°F	.02°F	64°F to 86°F	1 sec
	conductivity cell	± .1 $\frac{m\ mho}{cm}$	.06 $\frac{m\ mho}{cm}$	0 to 65	
		± .1 $\frac{m\ mho}{cm}$	.01 $\frac{m\ mho}{cm}$	0 to 10	
EG&G dew point hygrometer	controlled thermistor	± 1°F	.16°F	-40°F to 122°F	4°F/sec
Raytheon fathometer	Ba-Ti transducer	± 1 inch	.1 ft.	0 to 205 ft.	.1 sec
Lundy heading indicator	rotating flux gate	1°	1°	0° to 360°	.5 sec
Thunder Scientific air temperature	thermistor	± .5°F	.1°F	14°F to 104°F	
Braincon water temperature	thermistor	± .5°F	.06°F	28°F to 86°F	
Robinson-Halpern pressure sensor	diaphram and potentiometer	± 2%	.01 psig	0 to 6 psig	50 m sec to full scale
CM^2 salinometer	temperature compensated inductive cell	± .05 ppt	.01 ppt	0 to 20 ppt	5 sec.
Fisher-Porter tide guage	float type	± .01 ft.	.01 ft.	0 to 50 ft.	
Weather Measure pyranometer	thermopile	depends on standard voltage calibration	.01 ly/min	-.5 to 2.5 ly/min	20 sec. to full scale

APPENDIX E

RAW DATA PLOTS

Symbols

□	Water Temp. (1/2' depth)
△	Water Temp. (3' depth)
X	Water Temp. (6' depth)
○	Air Temp. (3' above water surface)
+	Air Temp. (6' above water surface)

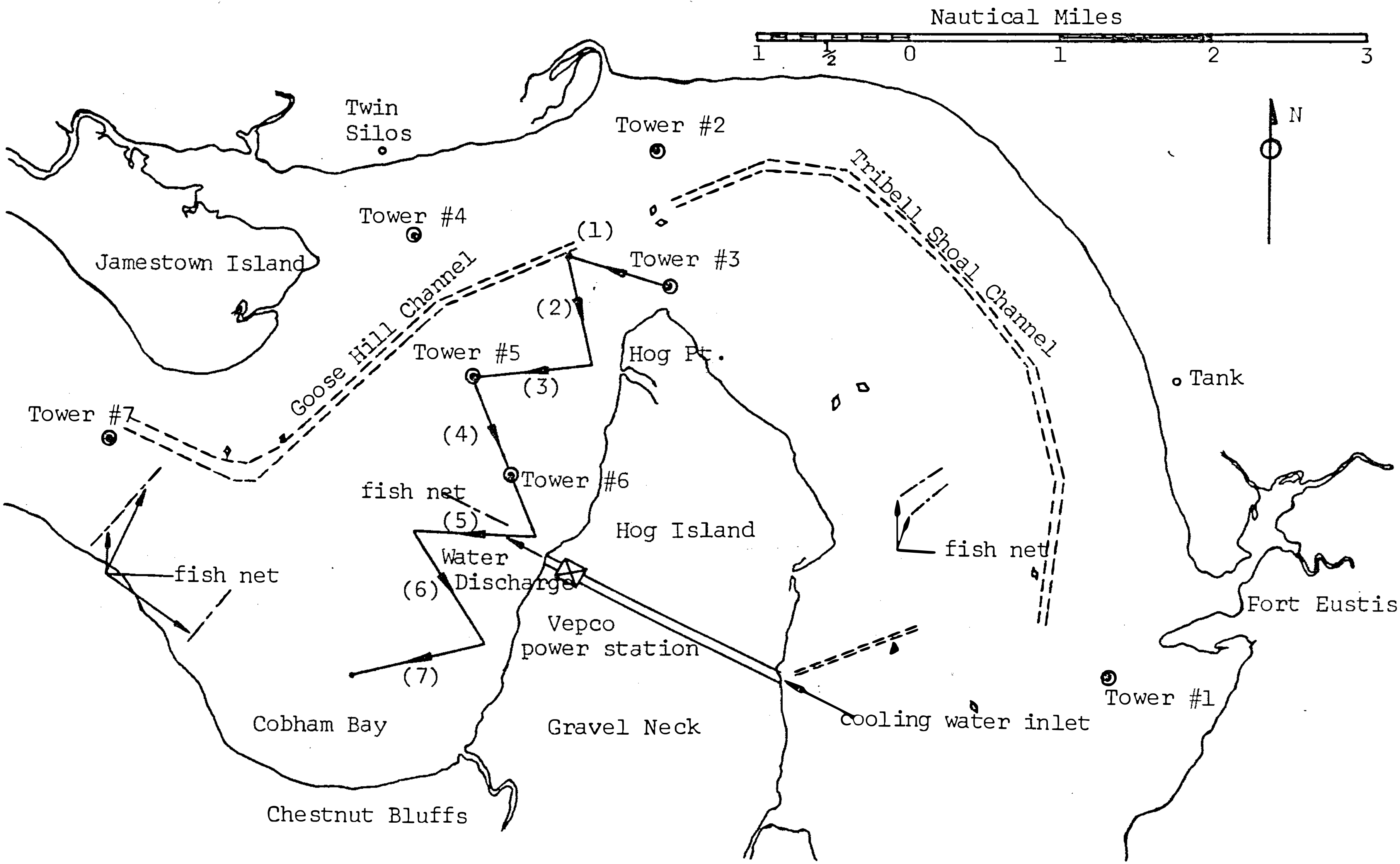
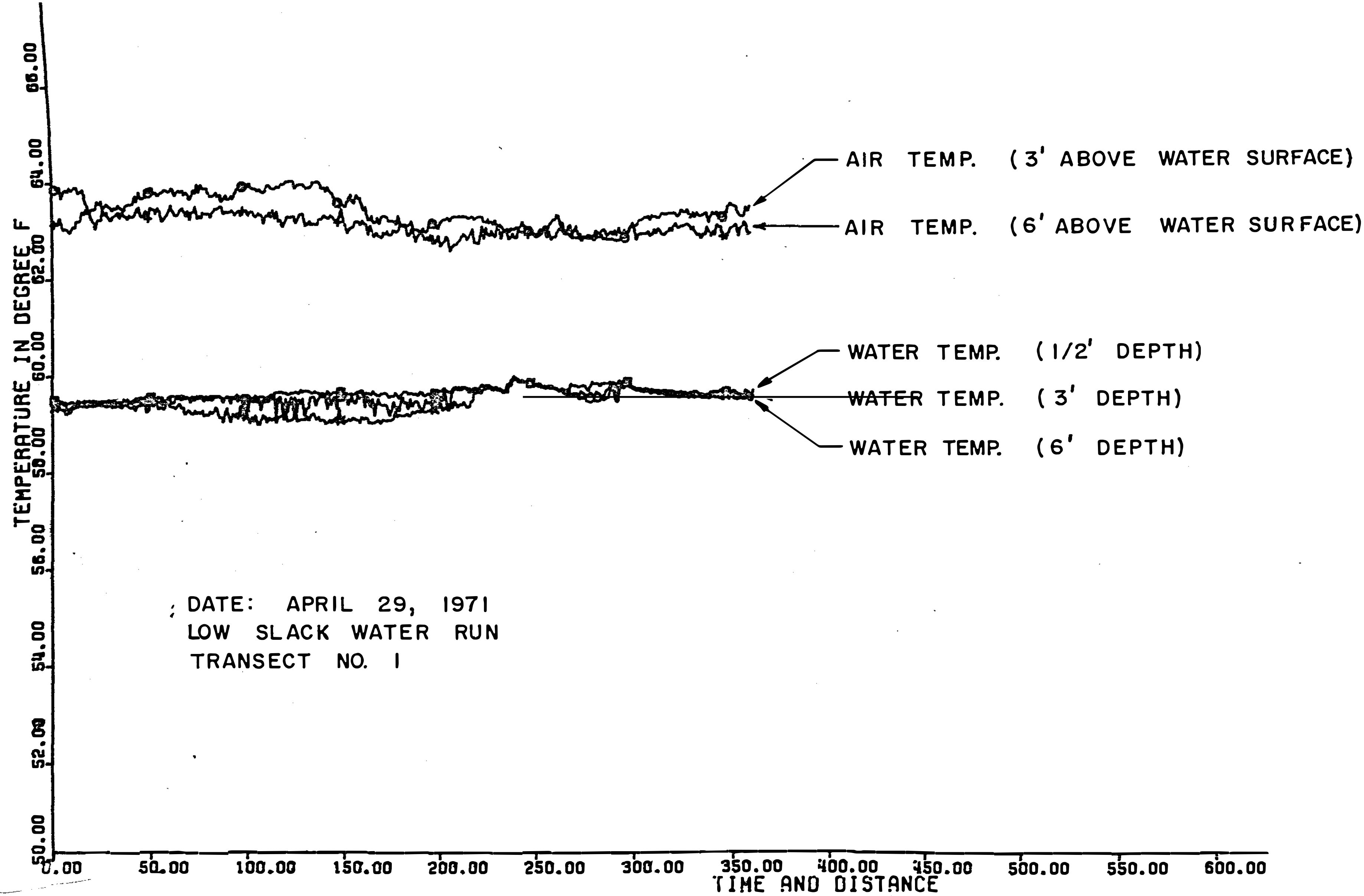
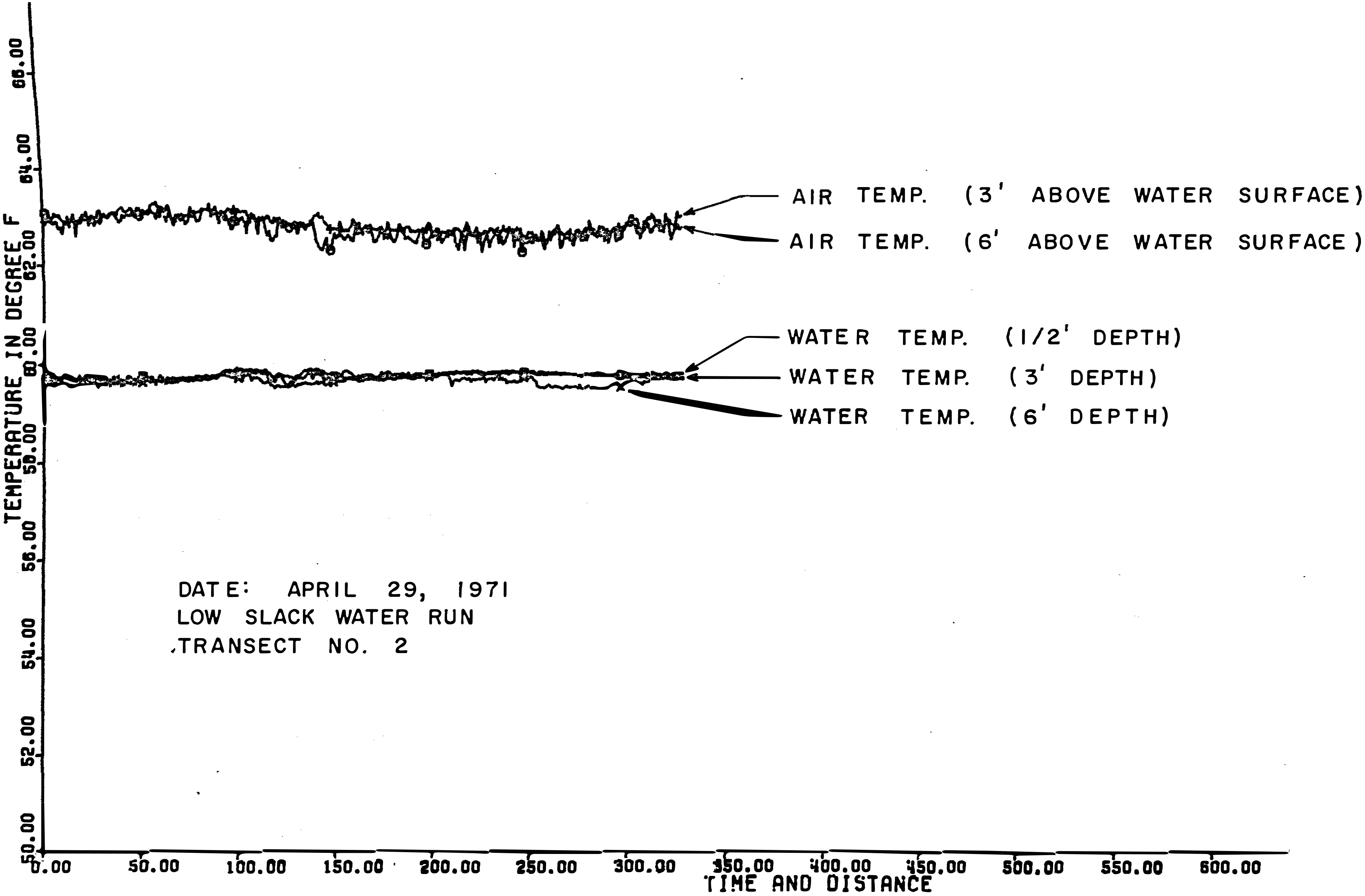
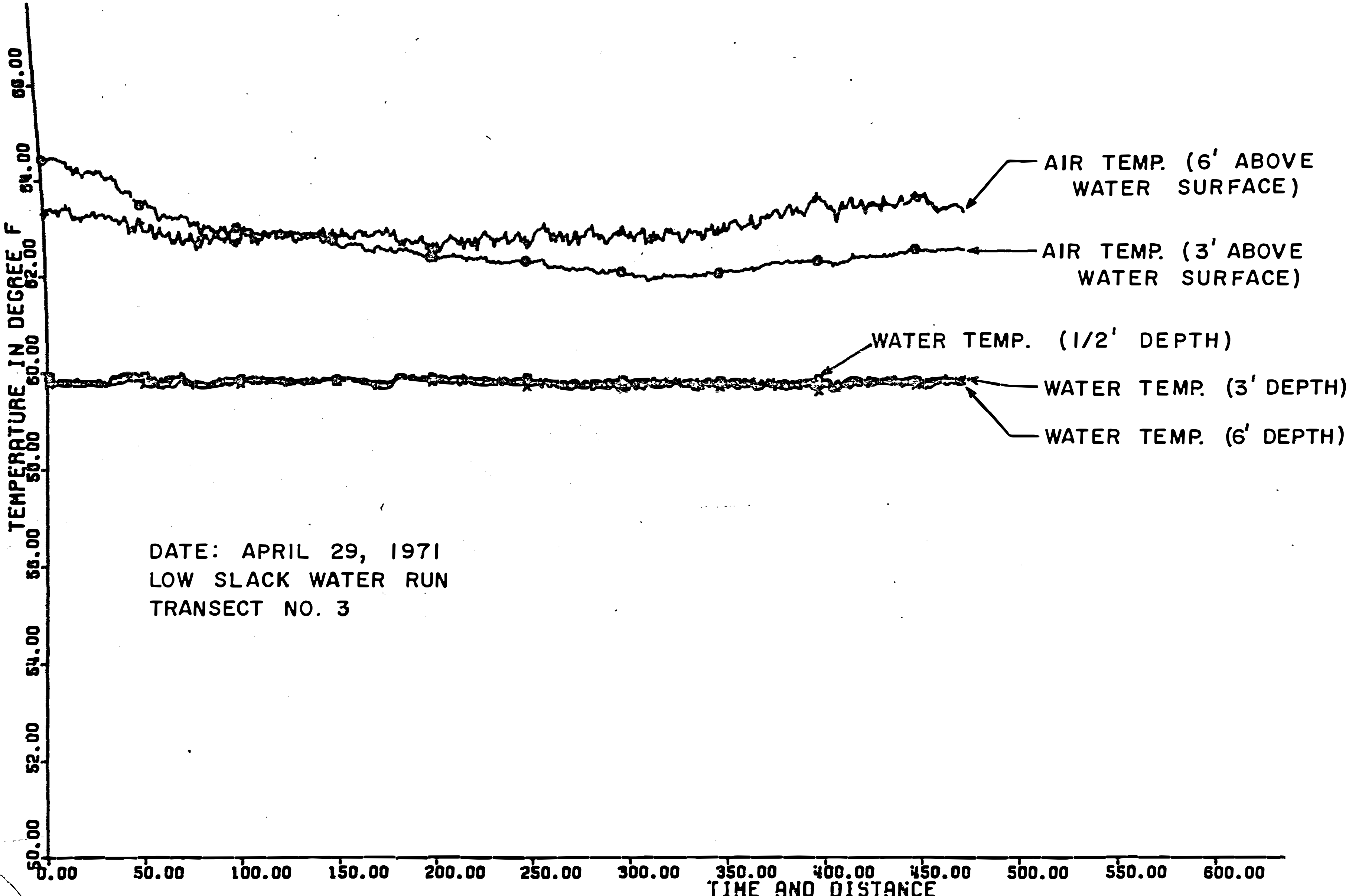
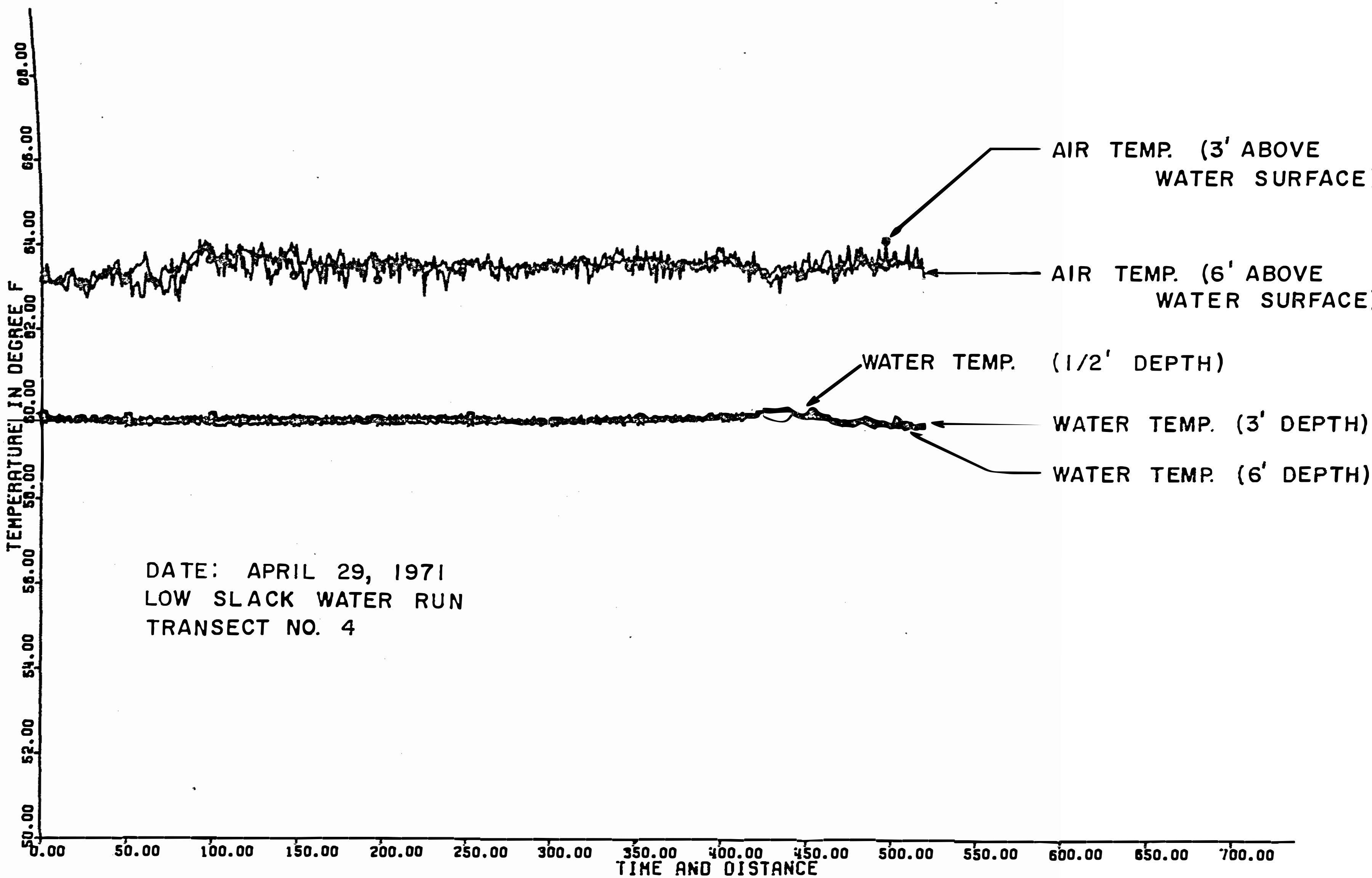


Figure 23. Transects location

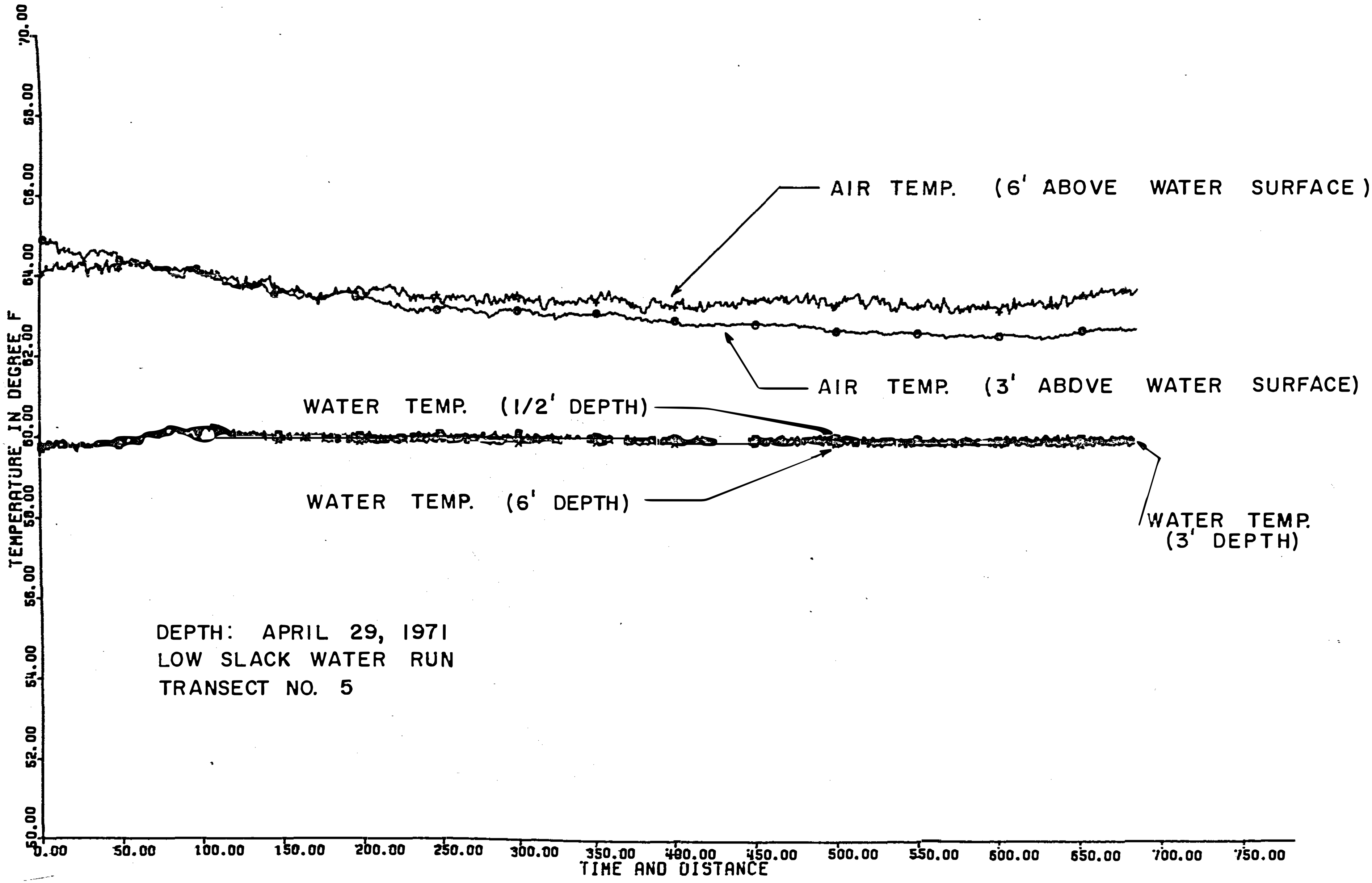

AIR TEMP. (3' ABOVE WATER SURFACE)
AIR TEMP. (6' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (3' DEPTH)
WATER TEMP. (6' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 1
TEMPERATURE IN DEGREE F
50.00
52.00
54.00
56.00
58.00
60.00
62.00
64.00
66.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
TIME AND DISTANCE

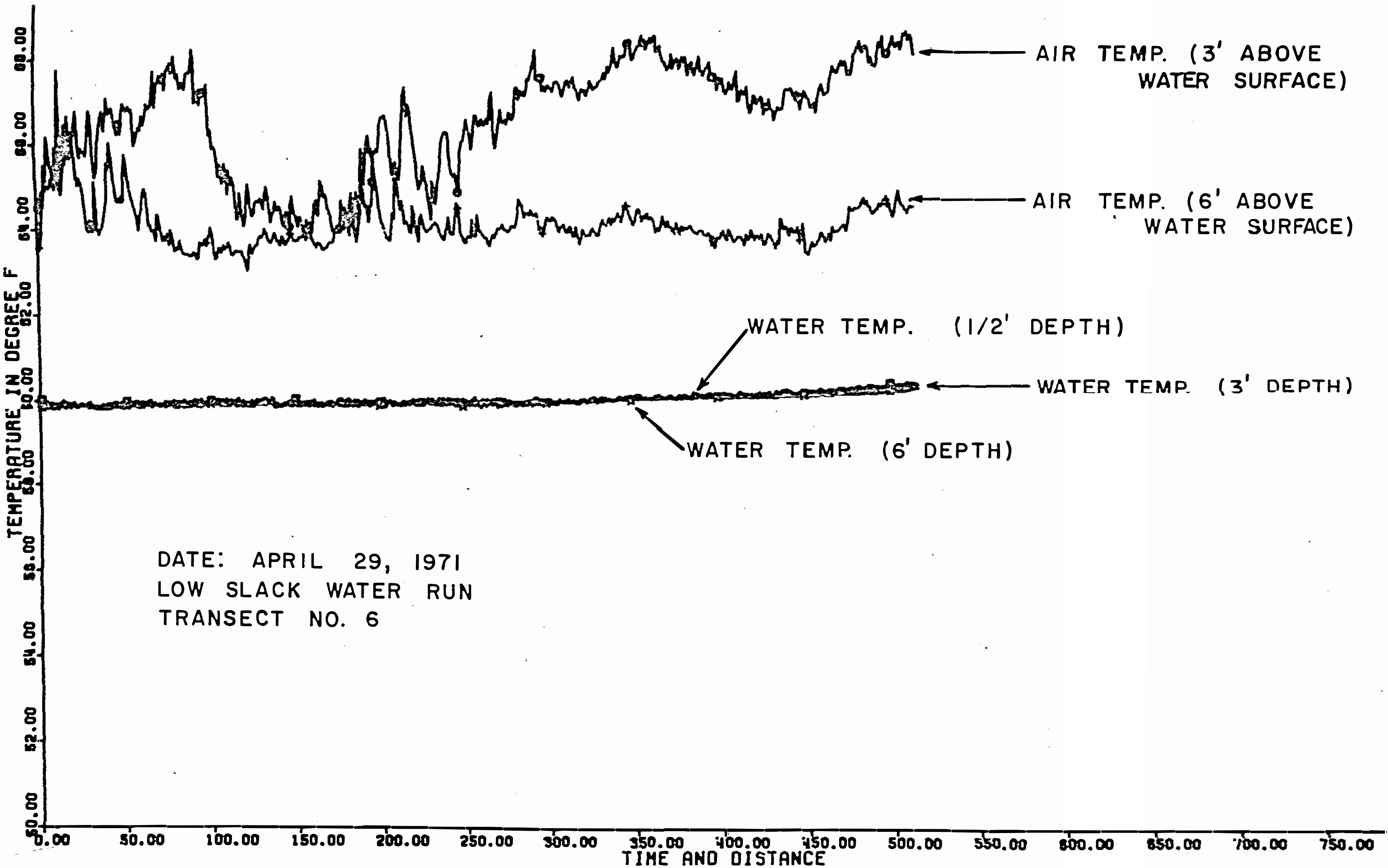

AIR TEMP. (3' ABOVE WATER SURFACE)
AIR TEMP. (6' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (3' DEPTH)
WATER TEMP. (6' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 2
TEMPERATURE IN DEGREE F
66.00
64.00
62.00
60.00
58.00
56.00
54.00
52.00
50.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
TIME AND DISTANCE

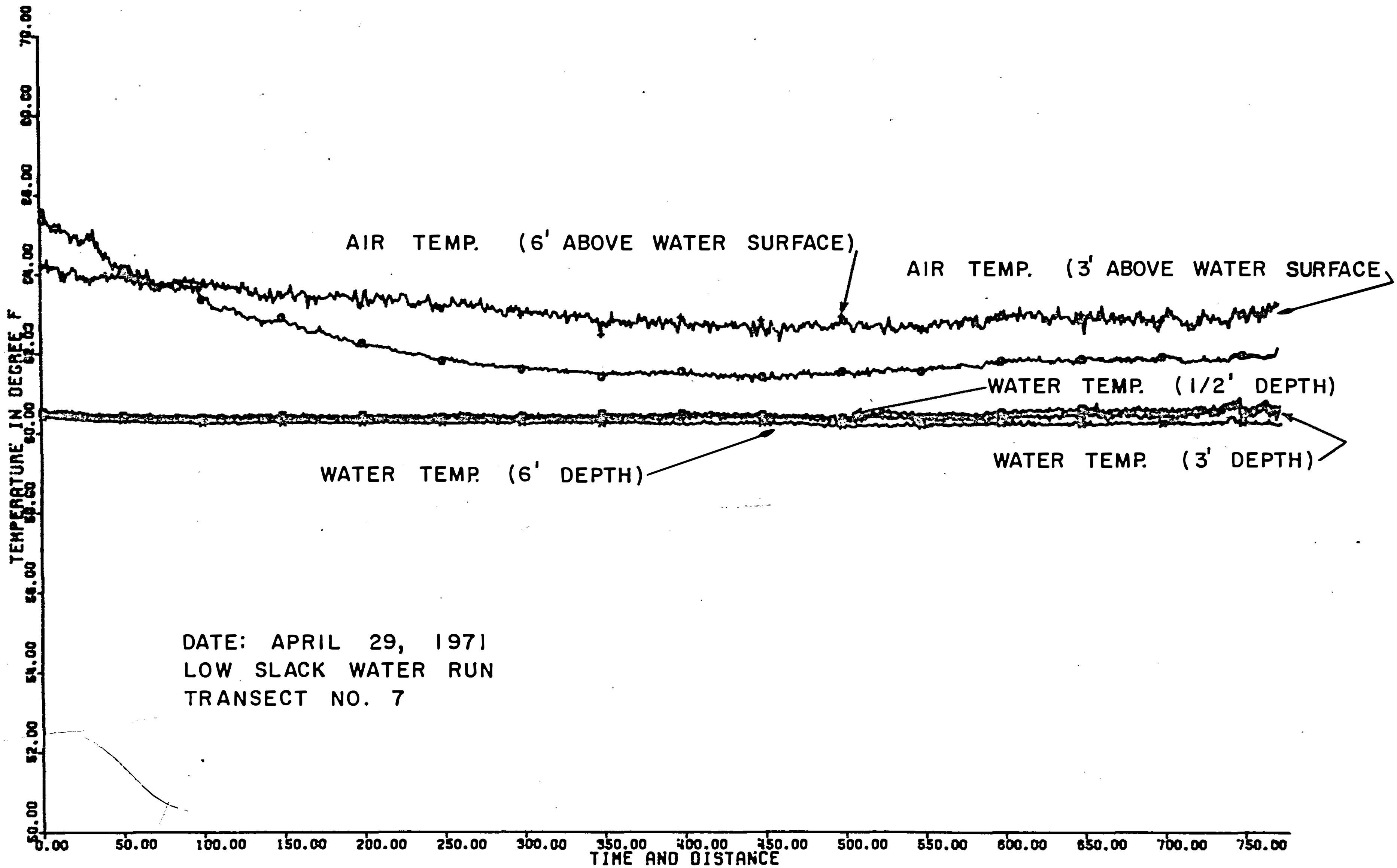

TEMPERATURE IN DEGREE F
50.00
52.00
54.00
56.00
58.00
60.00
62.00
64.00
66.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
TIME AND DISTANCE
AIR TEMP. (6' ABOVE WATER SURFACE)
AIR TEMP. (3' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (3' DEPTH)
WATER TEMP. (6' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 3



AIR TEMP. (3' ABOVE WATER SURFACE)
AIR TEMP. (6' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (3' DEPTH)
WATER TEMP. (6' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 4
TEMPERATURE IN DEGREE F
50.00
52.00
54.00
56.00
58.00
60.00
62.00
64.00
66.00
68.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
TIME AND DISTANCE


AIR TEMP. (6' ABOVE WATER SURFACE)
AIR TEMP. (3' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (6' DEPTH)
WATER TEMP. (3' DEPTH)
DEPTH: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 5
TEMPERATURE IN DEGREE F
70.00
68.00
66.00
64.00
62.00
60.00
58.00
56.00
54.00
52.00
50.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
TIME AND DISTANCE


AIR TEMP. (3' ABOVE WATER SURFACE)
AIR TEMP. (6' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (3' DEPTH)
WATER TEMP. (6' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 6
TEMPERATURE IN DEGREE F
62.00
54.00
52.00
50.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00
TIME AND DISTANCE


AIR TEMP. (6' ABOVE WATER SURFACE)
AIR TEMP. (3' ABOVE WATER SURFACE)
WATER TEMP. (1/2' DEPTH)
WATER TEMP. (6' DEPTH)
WATER TEMP. (3' DEPTH)
DATE: APRIL 29, 1971
LOW SLACK WATER RUN
TRANSECT NO. 7
TEMPERATURE IN DEGREE F
TIME AND DISTANCE
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
550.00
600.00
650.00
700.00
750.00

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